Appendix A Upper Watershed Hydrology Calibration

A.1 Introduction

The SacWAM model was calibrated in a multi-step process that covered the upper watersheds, the Sacramento Valley floor and CVP/SWP project operations. The first step was to calibrate the rainfall runoff processes in the catchments located upstream of the valley rim reservoirs as these calculations are independent of all other processes in the model. This involved tuning the Soil Moisture method hydrological parameters in the catchments until simulated and observed historical flows matched within an acceptable degree of tolerance. This calibration is described below. Following completion of the upper watershed calibration, the next step was to focus on processes occurring on the Sacramento Valley floor. This calibration is described in Appendix B.

The upper watersheds of SacWAM were calibrated by adjusting Soil Moisture Method hydrological parameters until stream flows agreed with DWR reported unimpaired flows. Calibration was performed at the following 21 locations (Figure A-1 and Figure A-2):

- American River at Fair Oaks
- Battle Creek
- Clear Lake Inflow
- Calaveras River near Bellota
- Clear Creek nr Igo
- Cosumnes River
- Cottonwood nr Olinda
- Cow Creek
- Elder Creek
- Feather River
- Jackson Creek
- Mokelumne River
- N Fork Cache Creek
- Paynes Creek
- Putah Creek
- Sacramento at Shasta
- Stony Creek
- Thomes Creek
- Trinity at Trinity Reservoir
- Yuba River at New Bullards Bar
- Yuba River at Englebright

The calibration period was water years 1970 – 2009, which represents both periods of high and low flow. The calibrated streams are the largest streams in the region. In the discussion below, flow statistics are presented for the 21 calibrated streams and an additional 17 smaller streams that were not calibrated.

Initially the snow parameters, crop coefficients, soil water capacity, deep water capacity, runoff resistance factor, root zone conductivity, deep conductivity, and preferred flow direction were set using parameters from the CVPA model. During calibration additional adjustments were made to all parameters except crop coefficients and runoff resistance factors. Comparison between simulated and observed flows at the locations shown in Figure A-1 and Figure A-2 were made using the Nash-Sutcliffe efficiency (E), root mean square error (RMSE)/Mean, and BIAS. These statistics were calculated using the following equations.

$$E = 1 - \frac{\sum_{i=1}^{n}(Q_{s,i} - Q_{o,i})^2}{\sum_{i=1}^{n}(Q_{o,i} - \bar{Q}_o)^2}$$

$$RMSE = \frac{100}{\overline{Q_o}}\sqrt{\frac{\sum_{i=1}^{n}(Q_{s,i} - Q_{o,i})^2}{n}}$$

$$BIAS = 100\,[(\overline{Q}_s - \overline{Q}_o)/\overline{Q}_o]$$

where:

n= number of months in the calibration period (480);

$Q_{s,i}$ = simulated monthly flow for time step i;

$Q_{o,i}$= observed monthly flow for time step i;

$\bar{Q}_o$= average of observed monthly flow values.

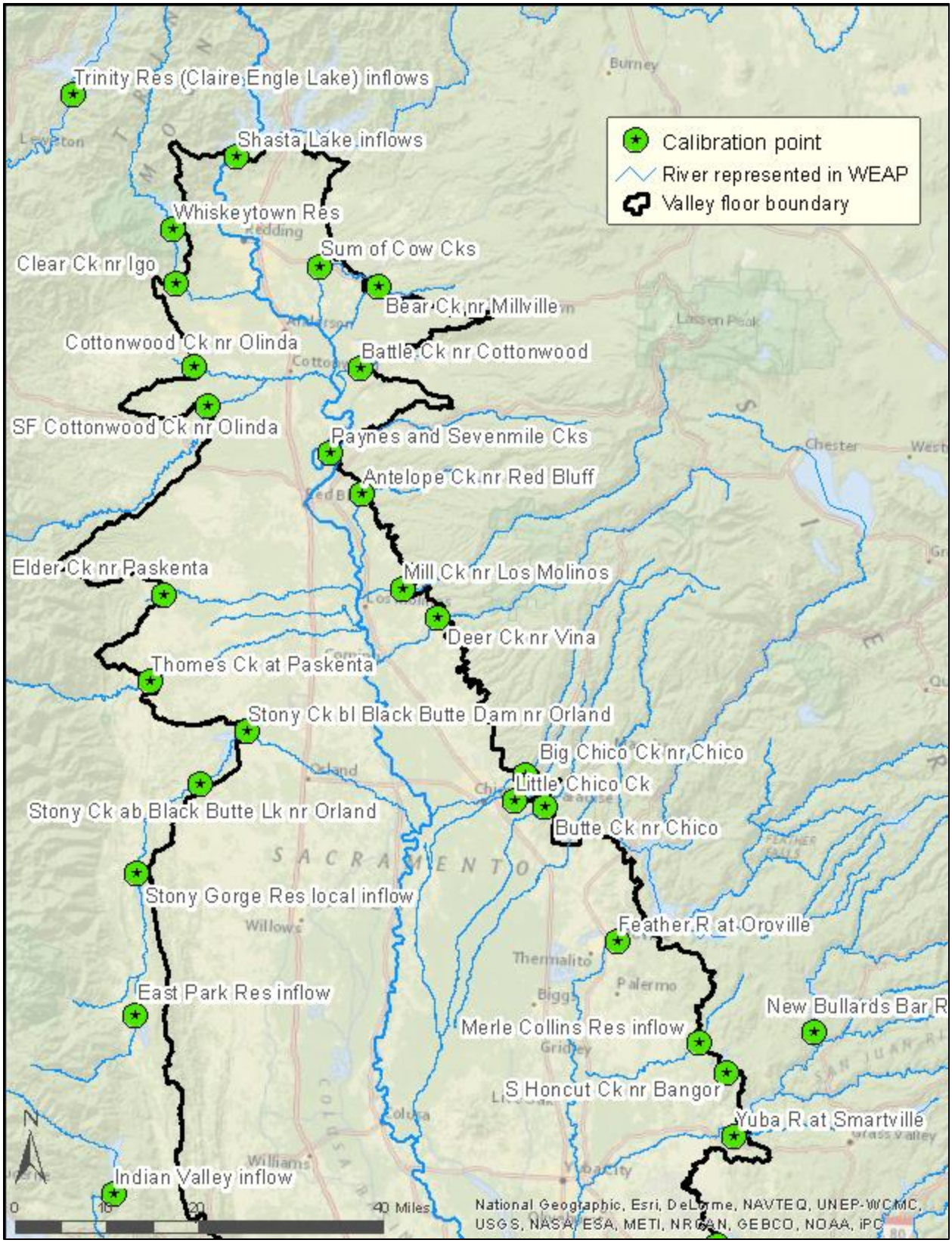

Figure A-1 Streamflow Calibration Points (North)

Figure A-2 Streamflow Calibration Points (South)

These adjustments were made based on an iterative approach in which the following steps were taken:

1. If a sub watershed had significant snow accumulation then the snow melt and freeze thresholds were adjusted so that the monthly average flow values peaked during the correct month. An additional effort was made to match simulated snow water equivalent values to recorded values at snow gauge locations similar to the approach described in Young et al. (2009). However, after an initial analysis was conducted, it was determined that the 500-meter elevation bands used in the model resulted in a simulated values that were too coarse to compare with point observations.
2. Simulated annual average flow volume was compared to observed values. If the simulated value was larger than observed then the soil water capacity and root zone conductivity were adjusted to increase the ET thereby reducing the stream flow. If the simulated value was smaller than observed then the soil water capacity and root zone conductivity were altered to decrease ET.
3. The simulated monthly average hydrograph was compared to the observed to determine if dry season low flows (July – Oct) were in agreement. If not, three parameters were adjusted. First, the preferred flow direction was altered to increase or decrease the amount of water flowing into the second compartment. Second, the deep water capacity and deep conductivity were adjusted until the decline in summer flows in the observation record were matched by the simulated values. Often, this resulted in smaller values of the deep water capacity and larger values of deep conductivity than the initial values, which resulted more rapid drainage of the deeper compartment.

The process used to arrive at the final calibration factors was a combination of manual and automated approaches. Preliminary exploration of the model performance was conducted by a brute force method in which the model was run over a range of parameter values. Maximum and minimum parameter values were set based on the author's experience. For each model run, the goodness of fit statistics discussed above were calculated. Following these automated model runs, plots of Nash Sutcliffe, BIAS, and RMSE/Mean were produced that showed which combinations of parameters resulted in the best model performance. In general, low values of model BIAS were favored over higher Nash Sutcliffe or lower RMSE/Mean values. Plots were also made of monthly average flows for each parameter combination. These graphs were inspected visually for goodness of fit. Once a set of parameters was selected from the brute force analysis, additional model runs were made either using the brute force approach with reduced parameter ranges or an automated parameter estimation process employing the PEST software was run.

The graphical results of the calibration can be found below. Plots of monthly flows, monthly average flows, annual flows, and flow exceedance are provided. Goodness of fit statistics are provided in Table A-1. Initial calibration efforts were focused on the largest rivers in the system including the upper Sacramento, Trinity, Feather, and American Rivers as well as tributaries that are of higher interest to SWRCB. Particular effort was made to keep the BIAS values close to zero. In future efforts, the accuracy of the runoff simulations for the smaller streams could be improved.

Table A-1 Upper Watershed Summary Statistics

Stream	BIAS	RMSE/Mean	NSE	Calibrated
American River at Fair Oaks	-3.0%	64.0%	74.1%	Y
Antelope Creek	-1.8%	60.2%	72.8%	N
Battle Creek	-5.6%	40.3%	62.2%	Y
Bear Creek	34.4%	63.4%	77.1%	N
Bear River at Camp Far West	3.1%	45.1%	91.2%	N
Big Chico Creek	2.5%	66.7%	83.3%	N
Butte Creek	-19.4%	62.5%	75.2%	N
Clear Lake Inflow	15.8%	69.6%	82.5%	Y
Calaveras River near Bellota	2.0%	72.9%	86.8%	Y
Clear Creek near Igo	-1.0%	56.2%	83.2%	Y
Cosumnes River	18.5%	73.4%	80.8%	Y
Cottonwood near Olinda	4.8%	49.5%	91.1%	Y
Cow Creek	2.2%	45.7%	89.6%	Y
Deer Creek	-5.2%	49.4%	81.1%	N
Dry Creek	72.0%	110.8%	70.8%	N
Dry and Hutchinson	48.5%	98.1%	69.5%	N
Elder Creek	12.8%	93.8%	69.1%	Y
Feather River	-0.5%	50.3%	78.6%	Y
French Dry Creek	125.0%	180.9%	-14.3%	N
Honcut Creek	74.9%	228.4%	35.9%	N
Jackson Creek	29.6%	86.6%	73.2%	Y
Kellogg Creek	227.7%	333.1%	-21.2%	N
Little Chico Creek	3.2%	74.0%	83.7%	N
Little Stony Creek	-2.2%	101.7%	62.6%	N
Littlejohns Creek	-8.1%	177.5%	41.4%	N
Marsh Creek	19.6%	204.2%	45.4%	N
Mill Creek	-5.6%	52.6%	60.6%	N
Mokelumne River	2.4%	63.1%	74.1%	Y
North Fork Cache Creek	13.4%	99.0%	74.1%	Y
Paynes Creek	-2.4%	69.7%	83.7%	Y
Putah Creek	29.3%	87.3%	82.1%	Y
Sacramento at Shasta	0.7%	31.7%	85.9%	Y
South Fork Cottonwood	-33.6%	77.9%	77.9%	N
Stony Creek	-13.3%	81.2%	80.0%	Y
Thomes Creek	29.8%	99.1%	53.8%	Y
Trinity at Trinity Reservoir	-1.9%	59.4%	69.6%	Y
Yuba River at NBB	4.6%	59.9%	74.7%	Y
Yuba River at Englebright	9.3%	57.6%	76.0%	Y

Key: N=No; NBB=New Bullards Bar NSE=Nash-Sutcliffe Efficiency; RMSE=root mean square error; Y=yes.

In the charts below, “Historical” represents full natural flows; “Simulated” represents simulated natural flows with all upstream operations removed.

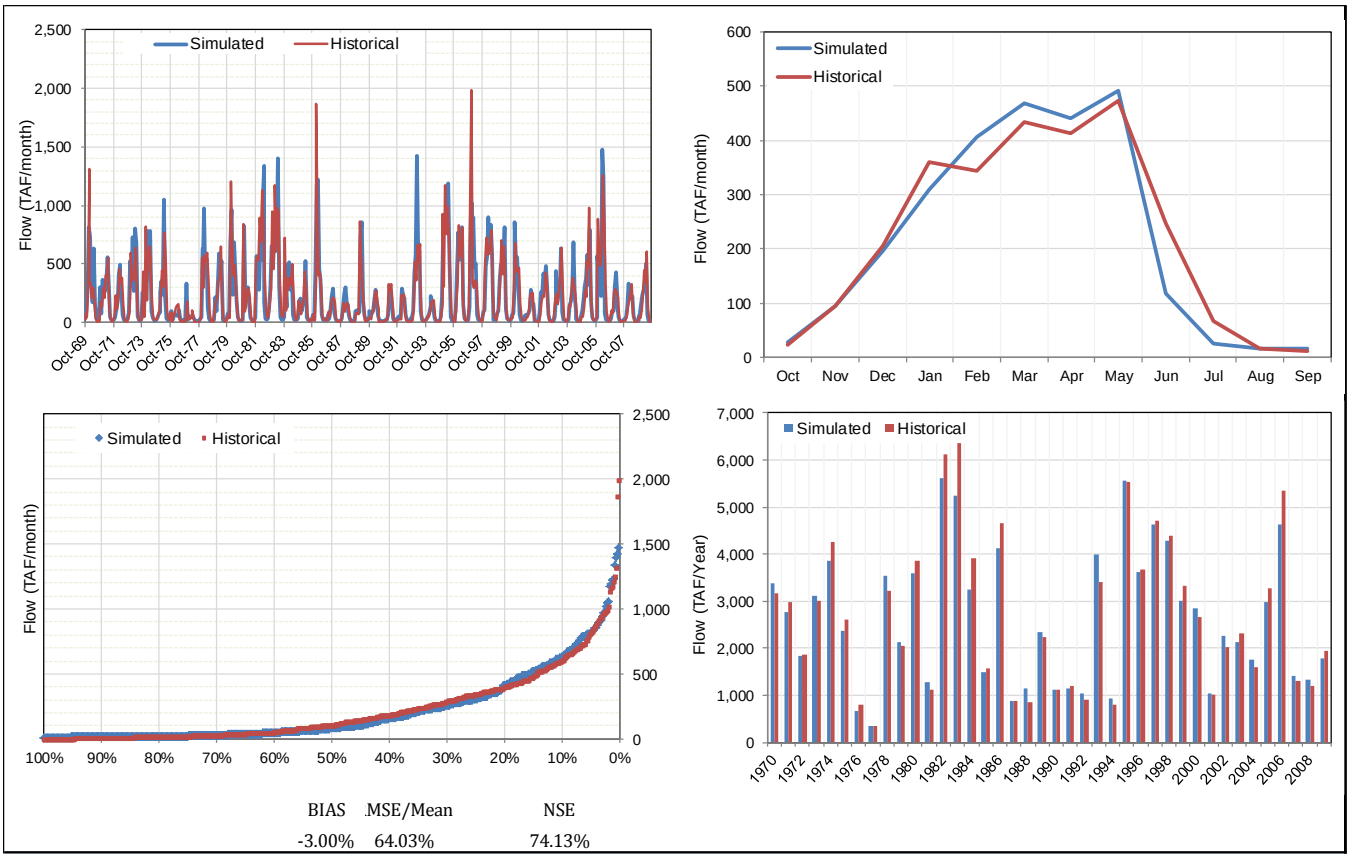

Figure A-3 American at Fair Oaks

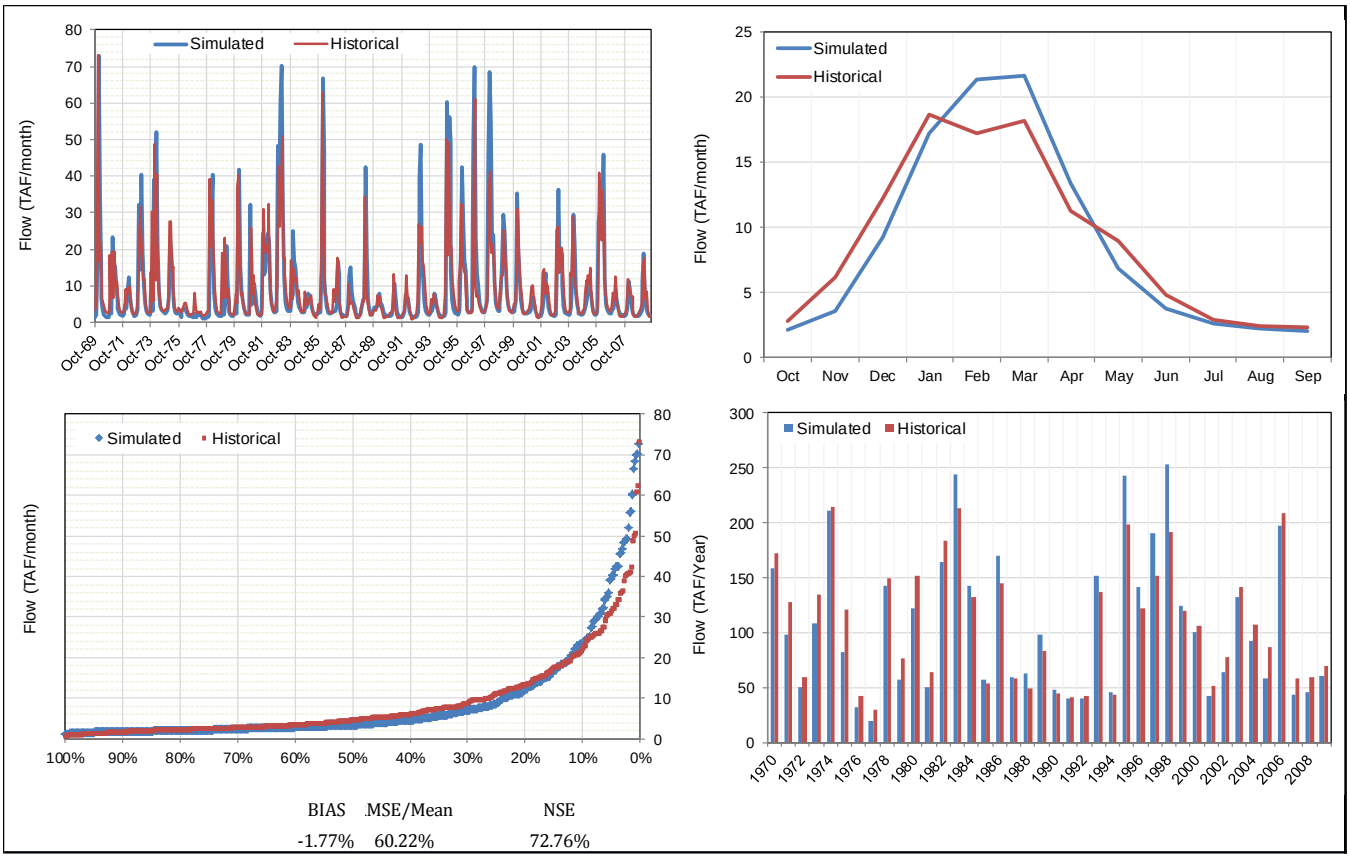

Figure A-4 Antelope Ck nr Red Bluff

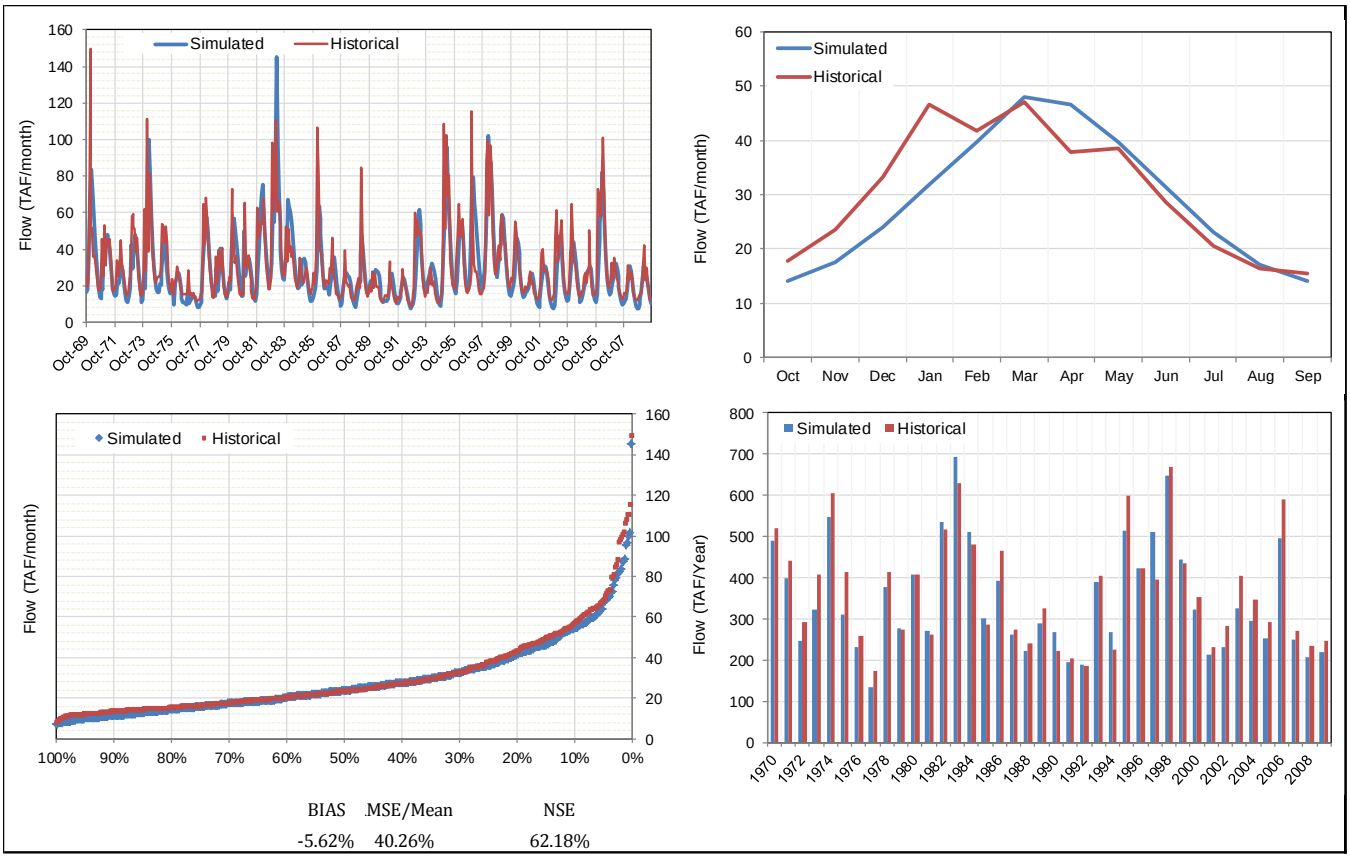

Figure A-5 Battle Ck nr Cottonwood

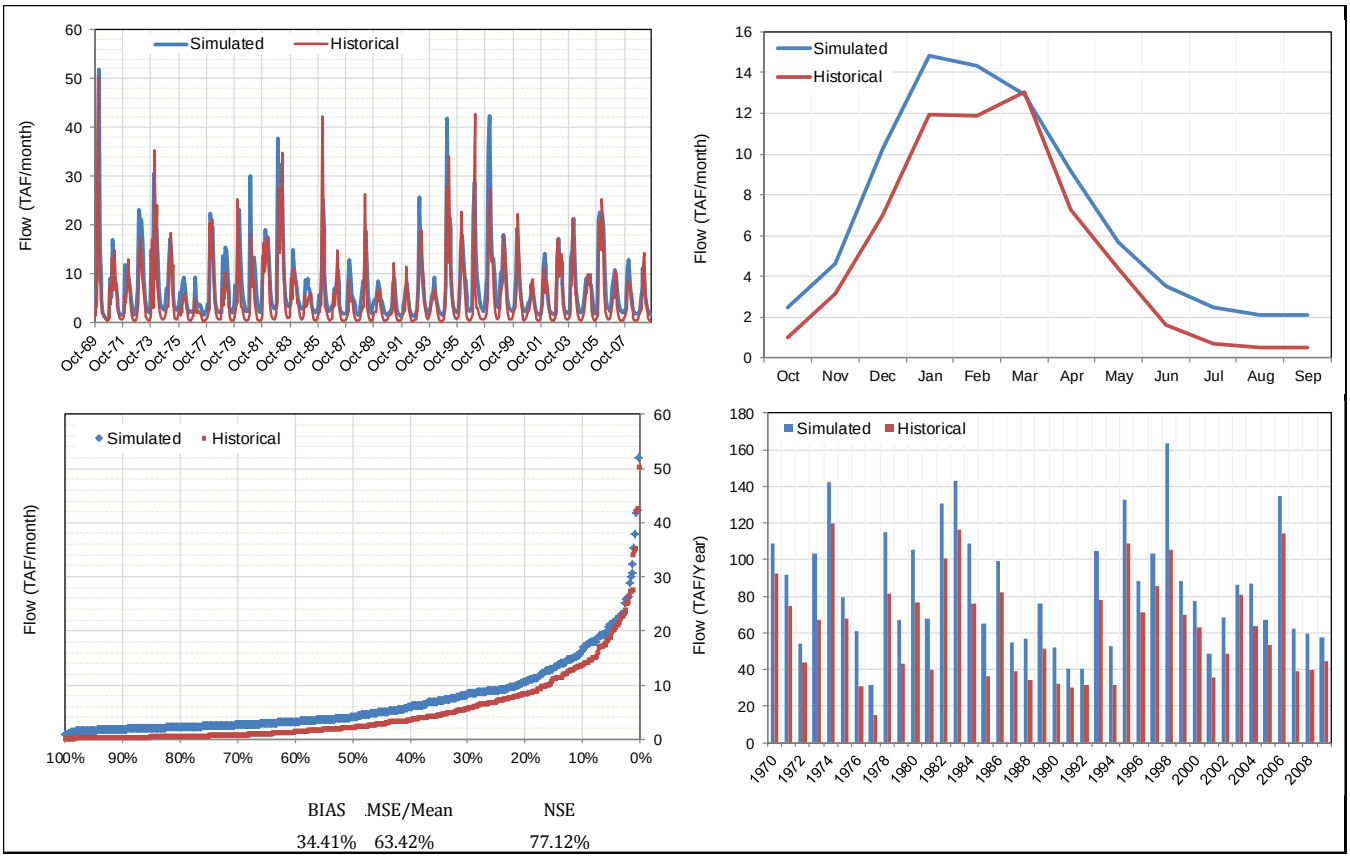

Figure A-6 Bear Ck nr Millville

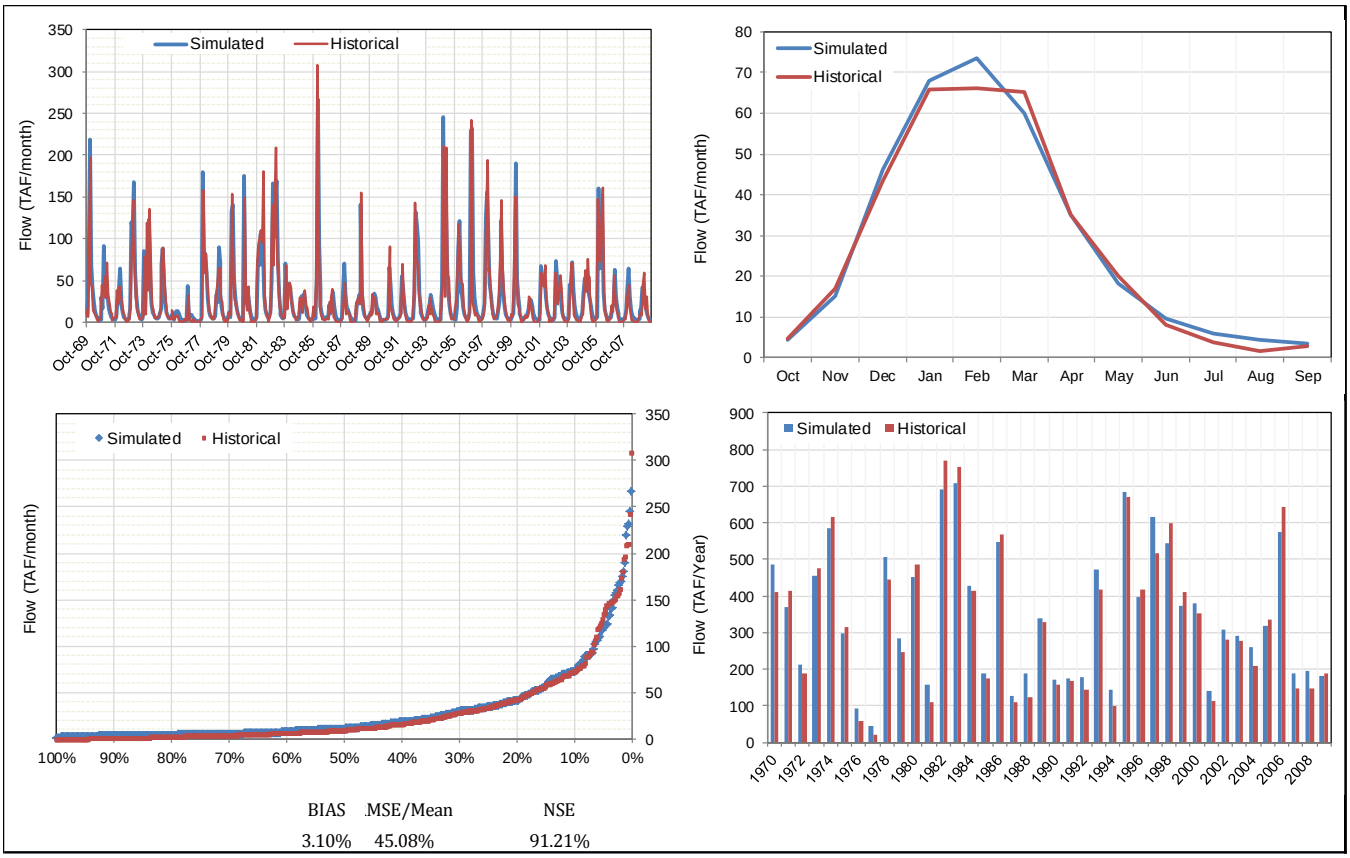

Figure A-7 Bear River at Camp Far West

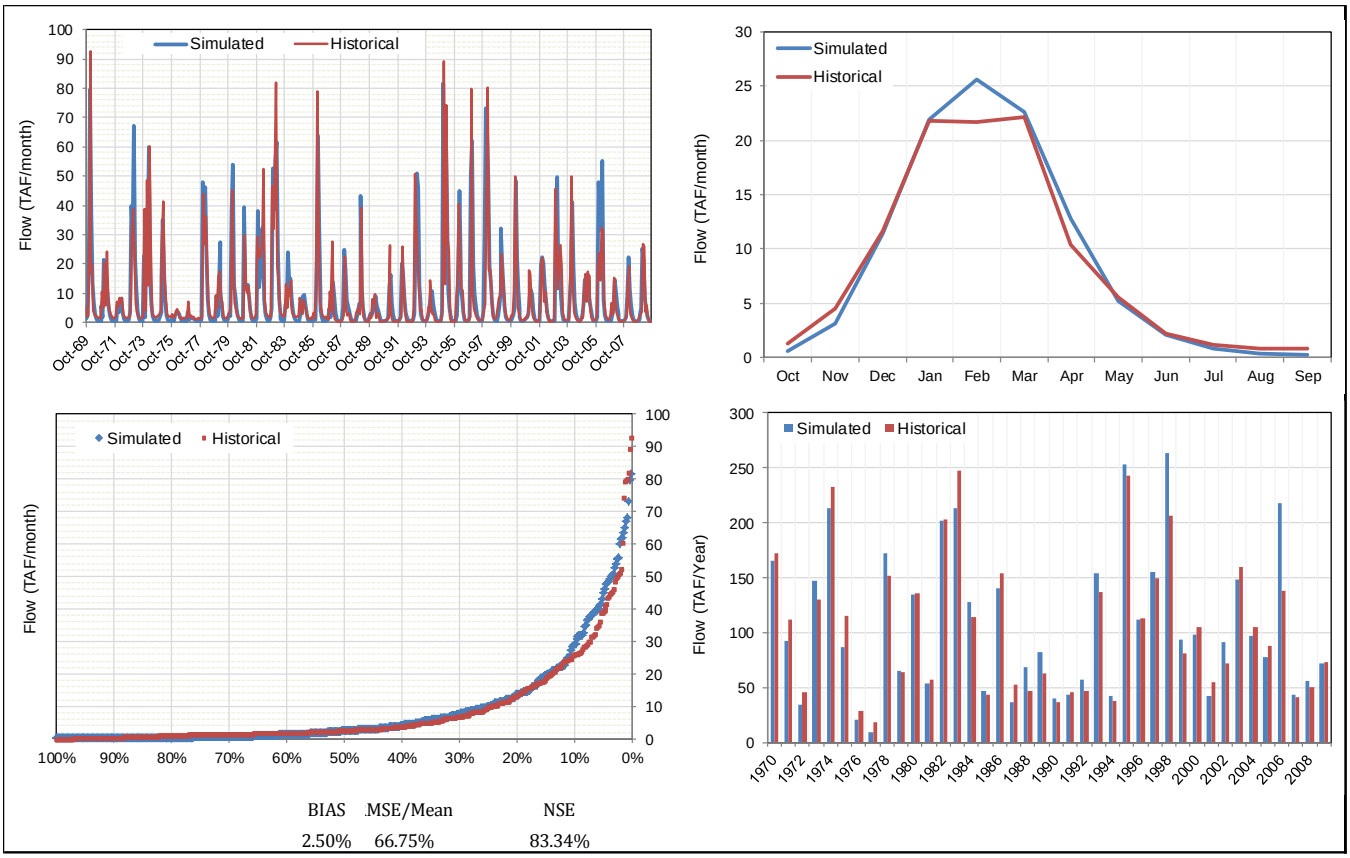

Figure A-8 Big Chico Ck nr Chico

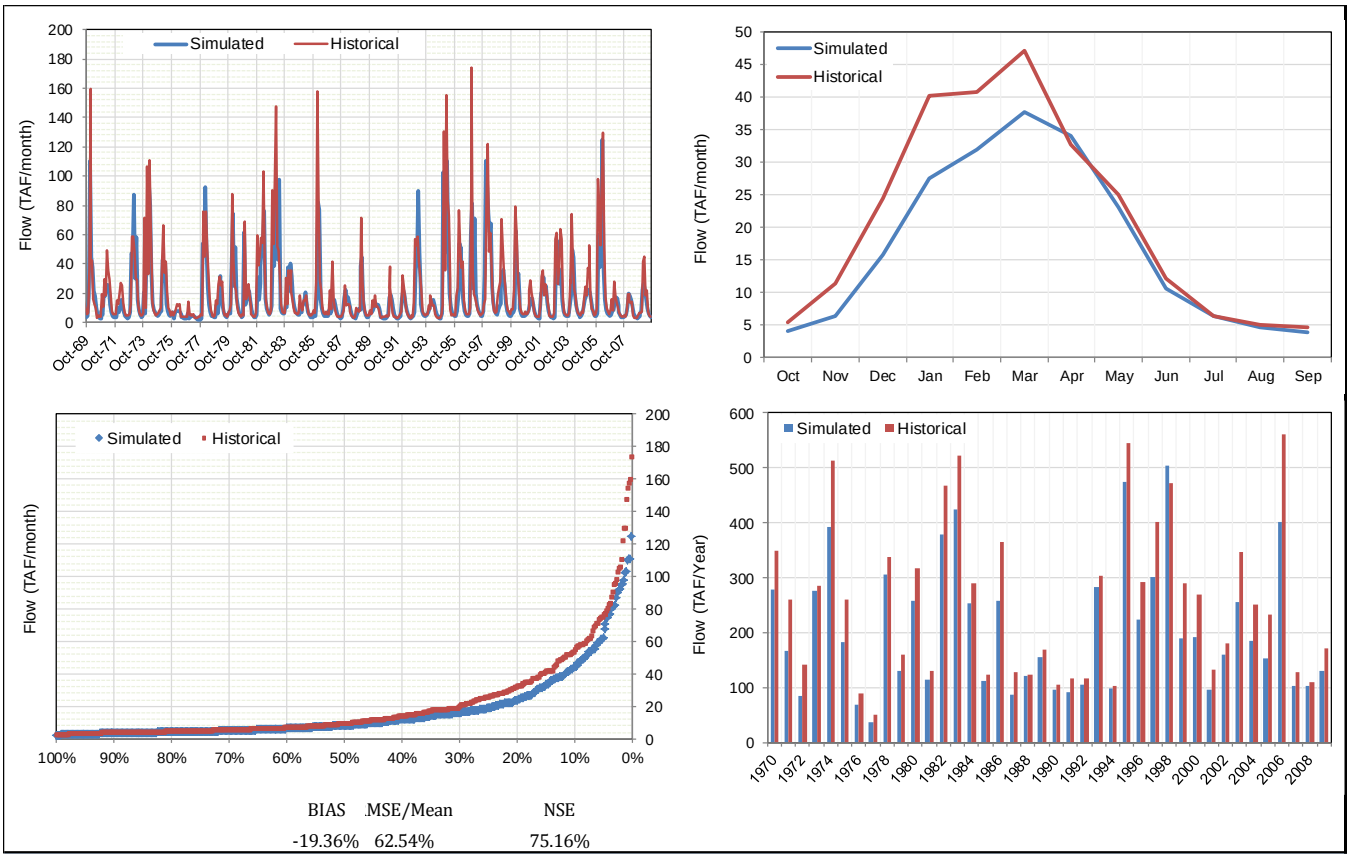

Figure A-9 Butte Ck nr Chico

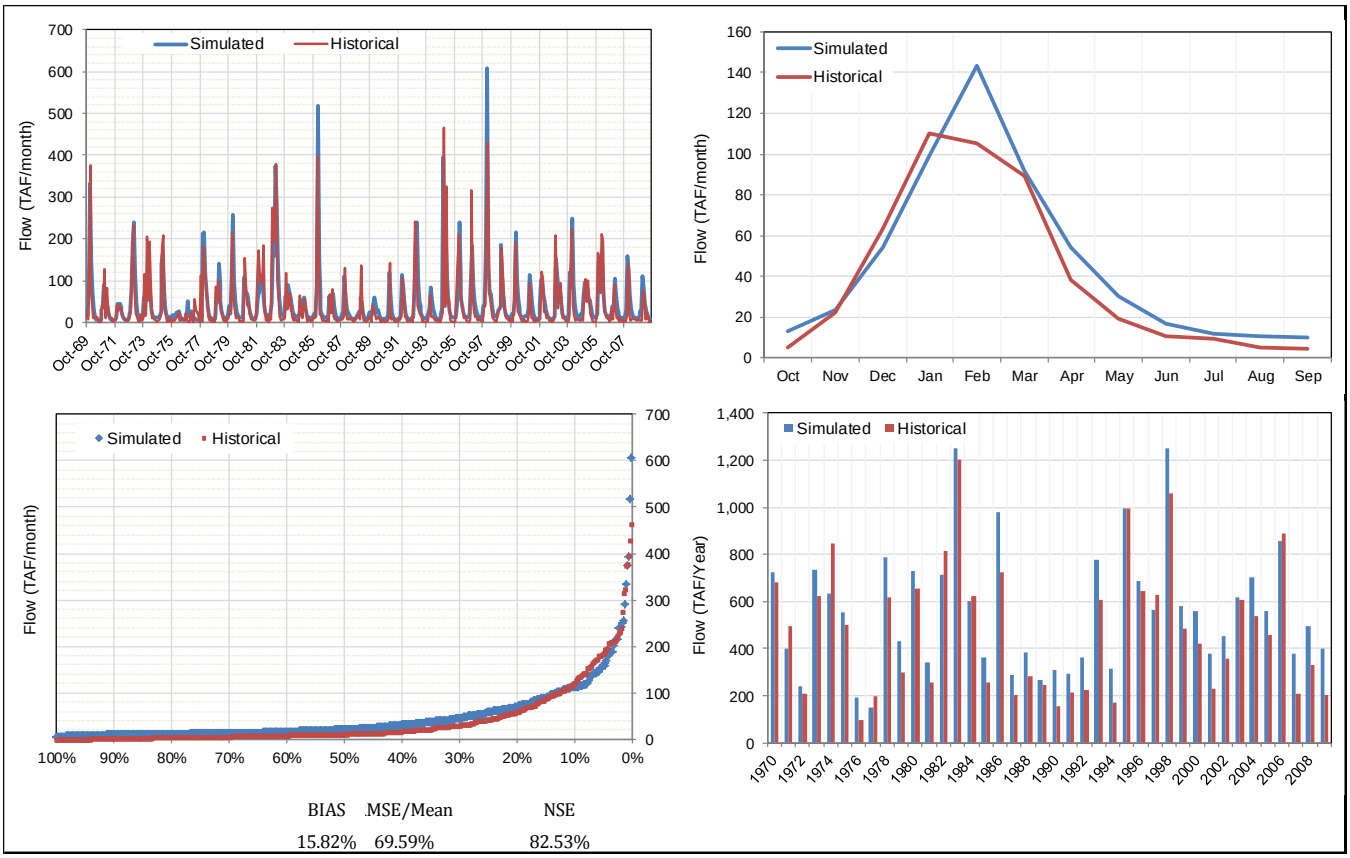

Figure A-10 Clear Lake Inflows

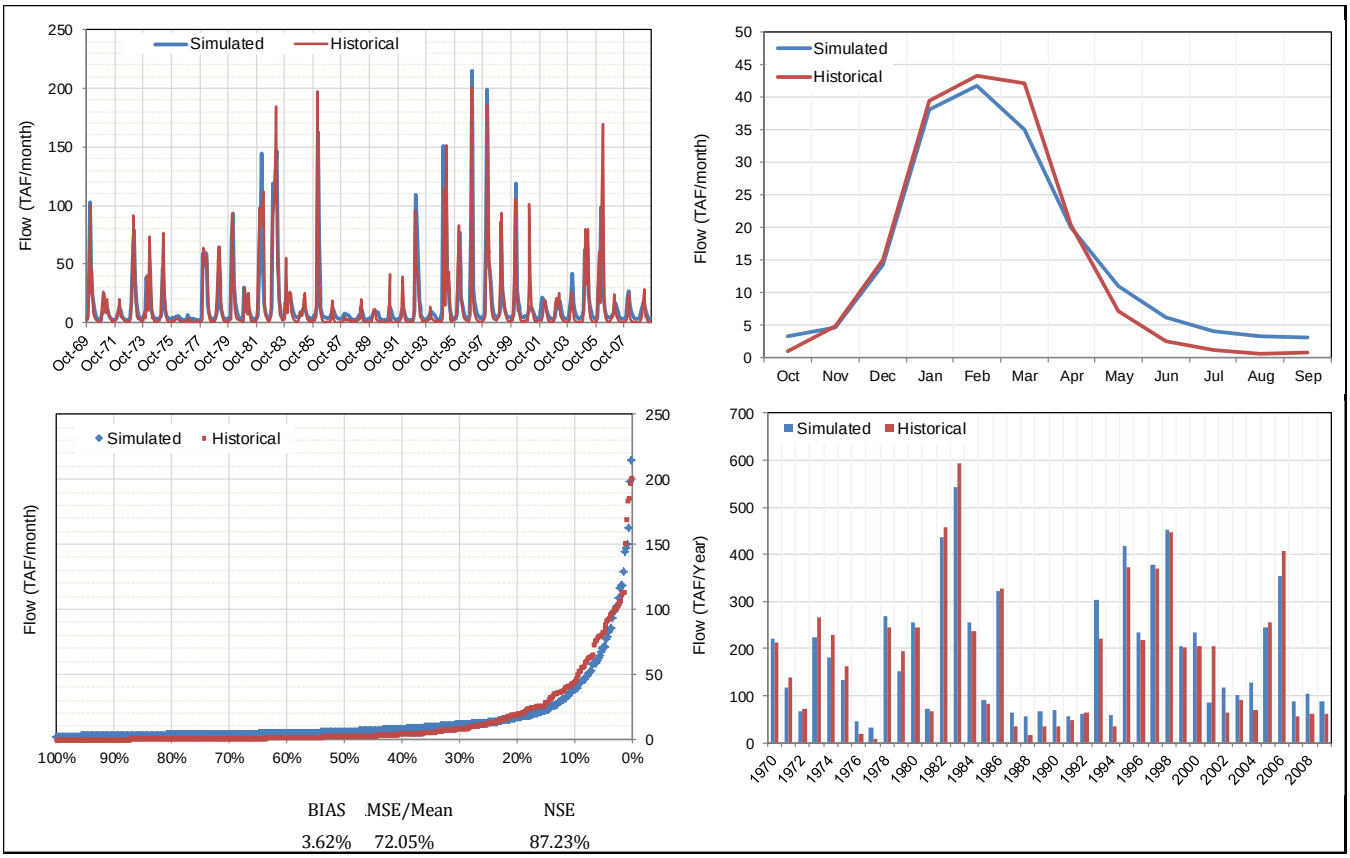

Figure A-11 Calaveras nr Bellota

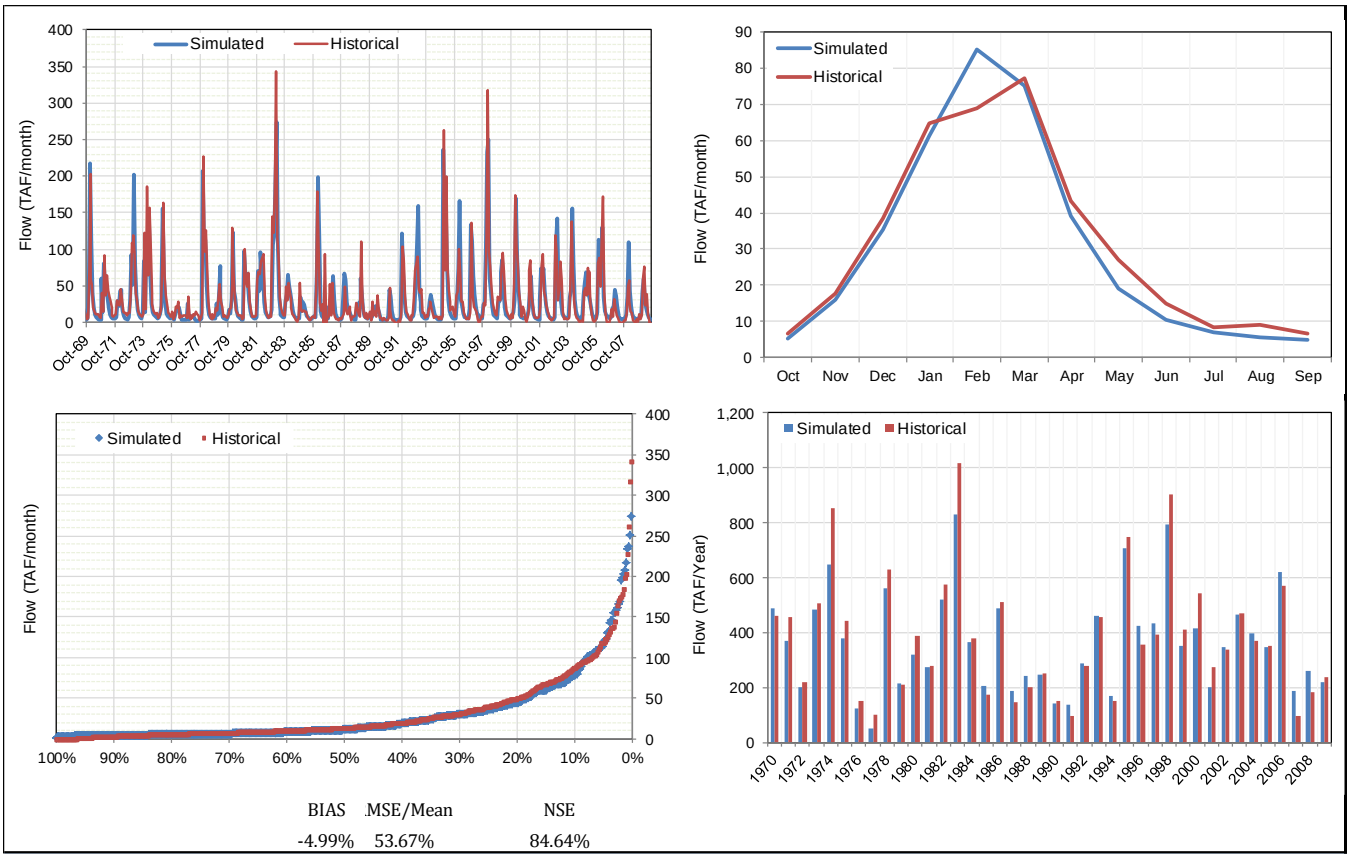

Figure A-12 Clear Creek nr Igo

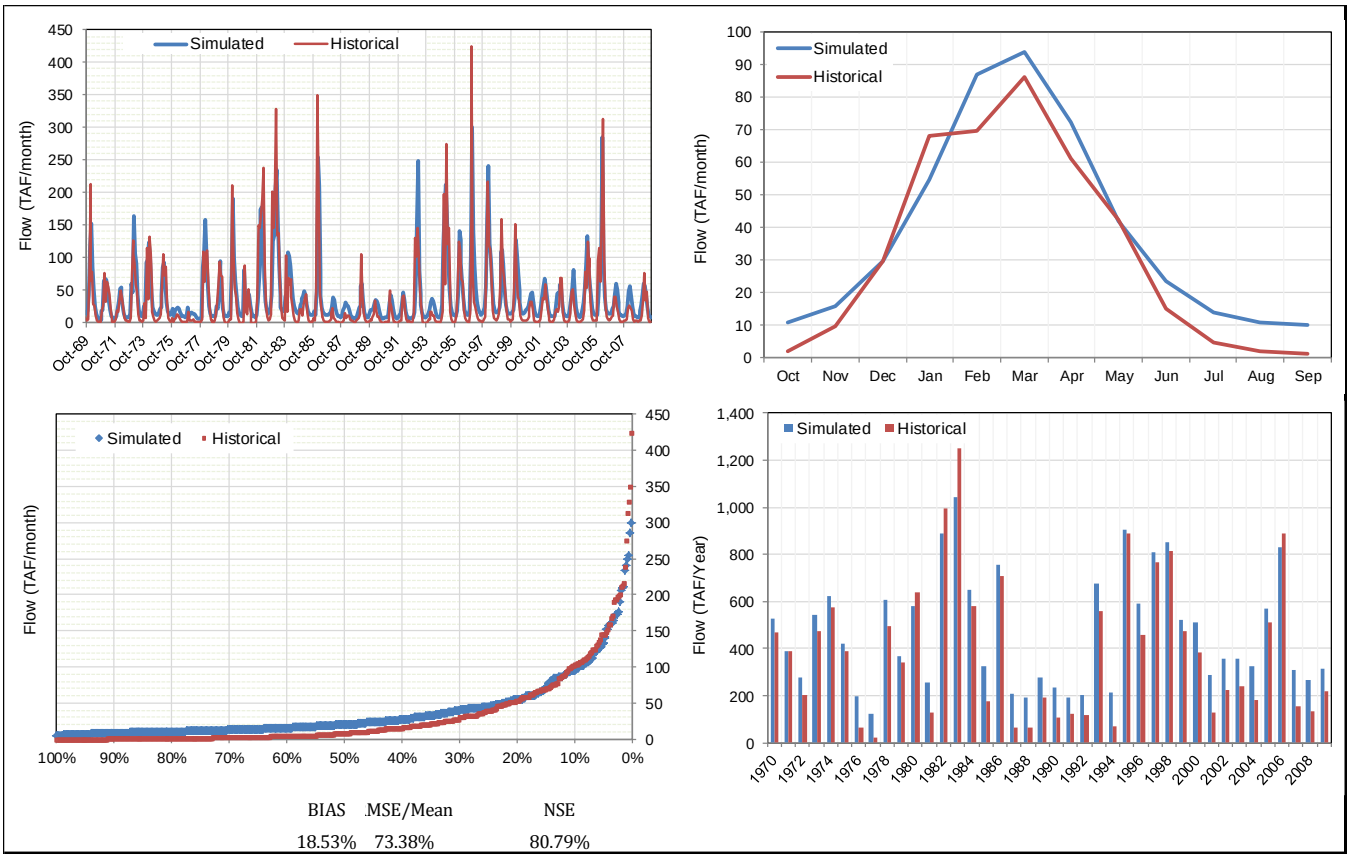

Figure A-13 Cosumnes at Michigan Bar

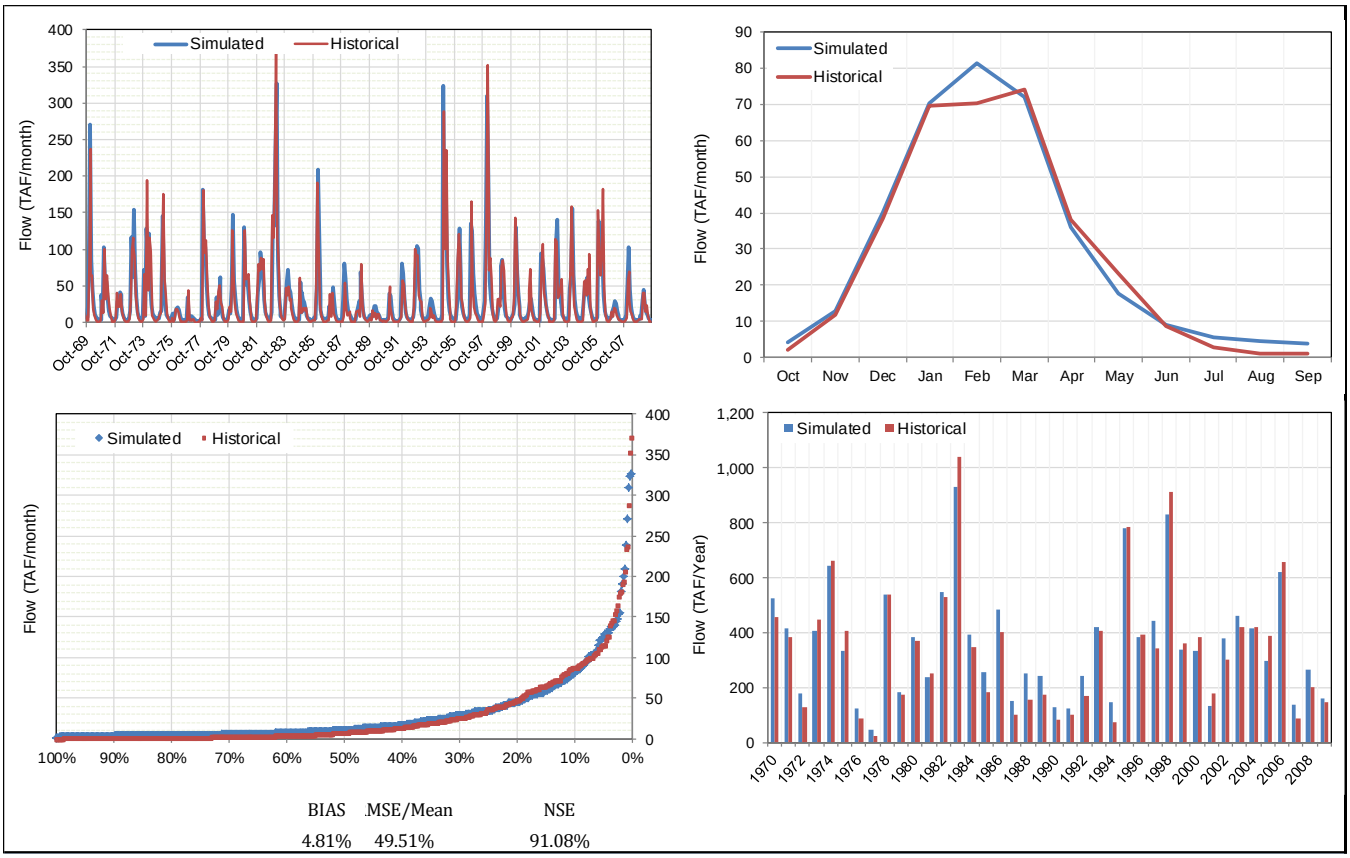

Figure A-14 Cottonwood Ck nr Olinda

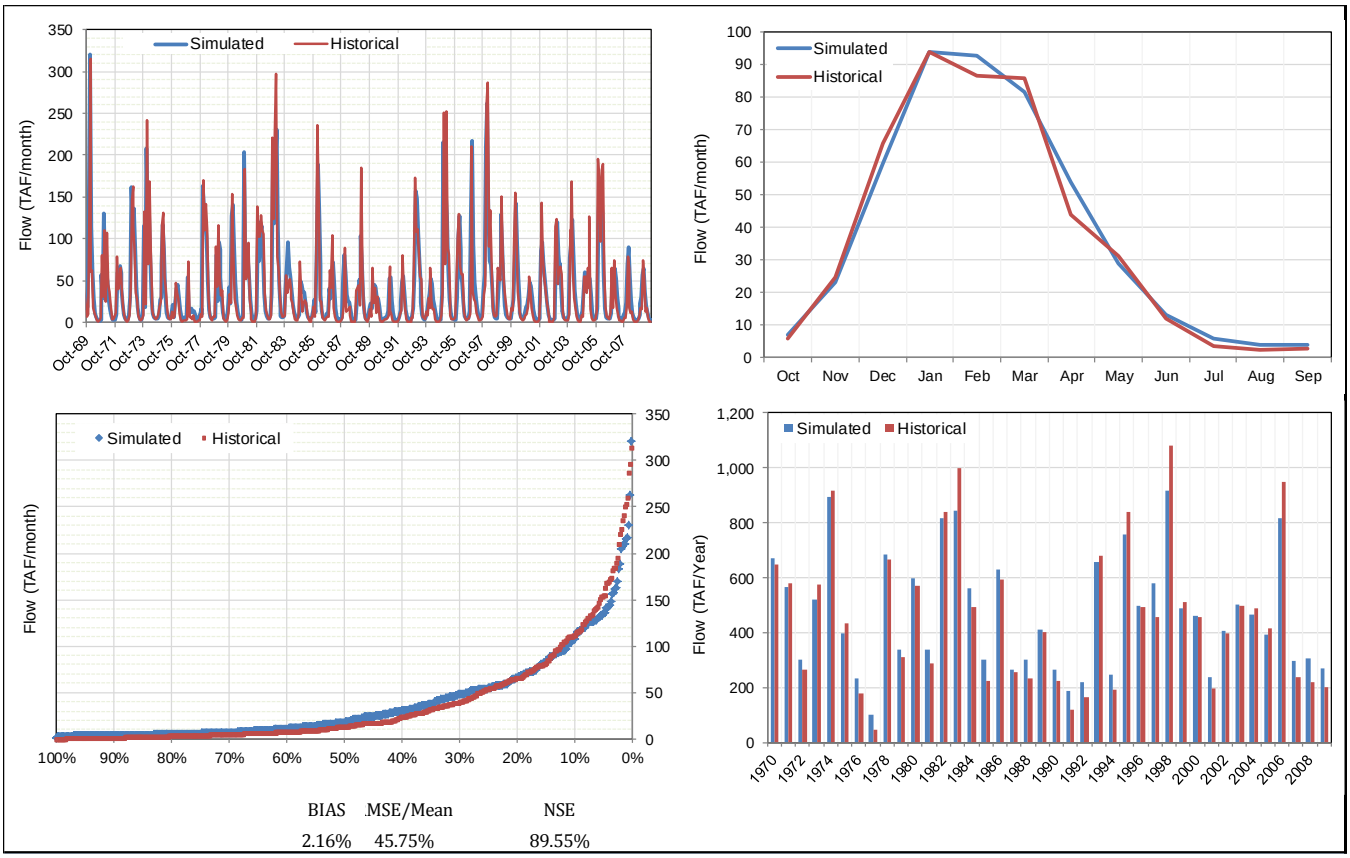

Figure A-15 Cow Ck at RM 14

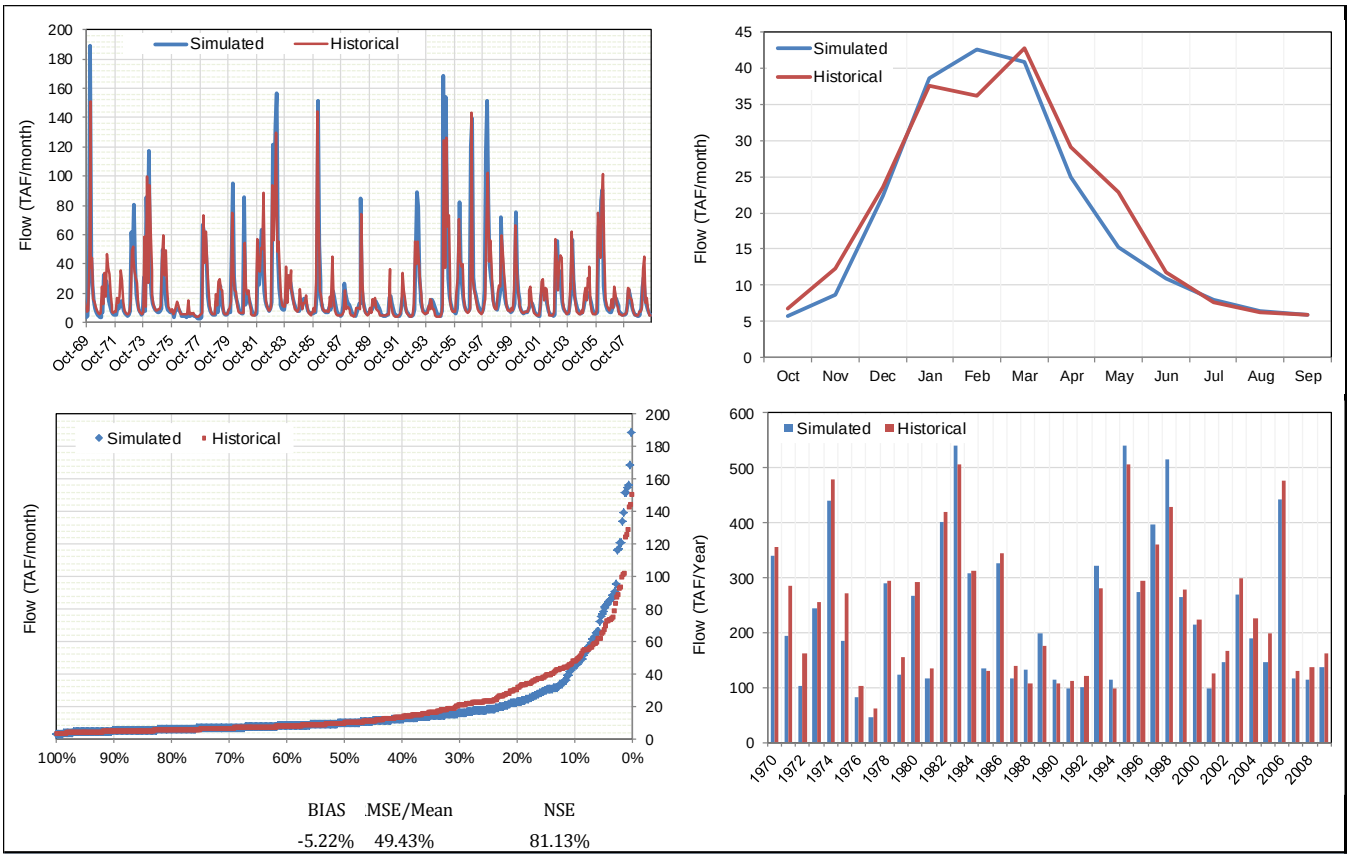

Figure A-16 Deer Ck nr Vina

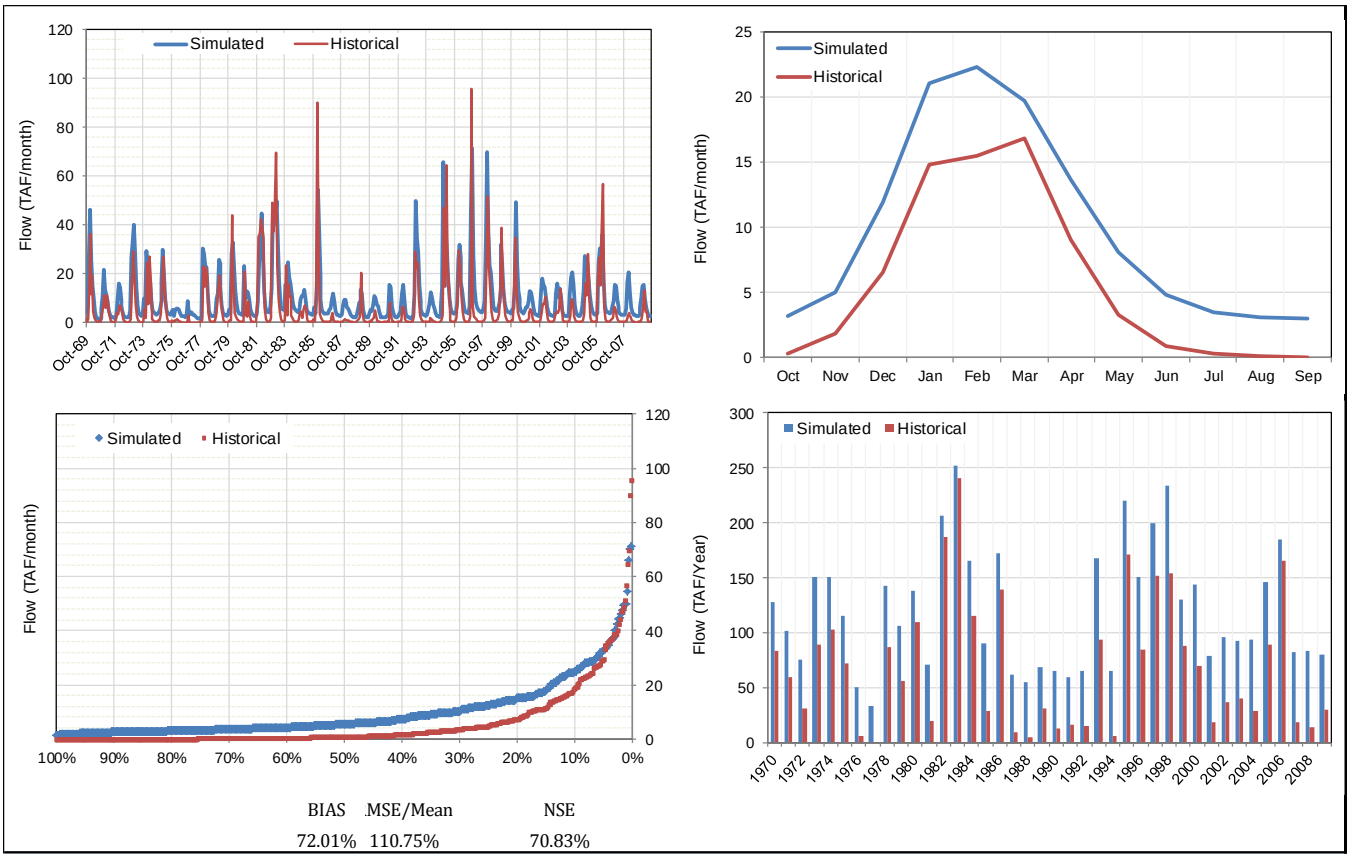

Figure A-17 Dry Ck (tributary to the Mokelumne River)

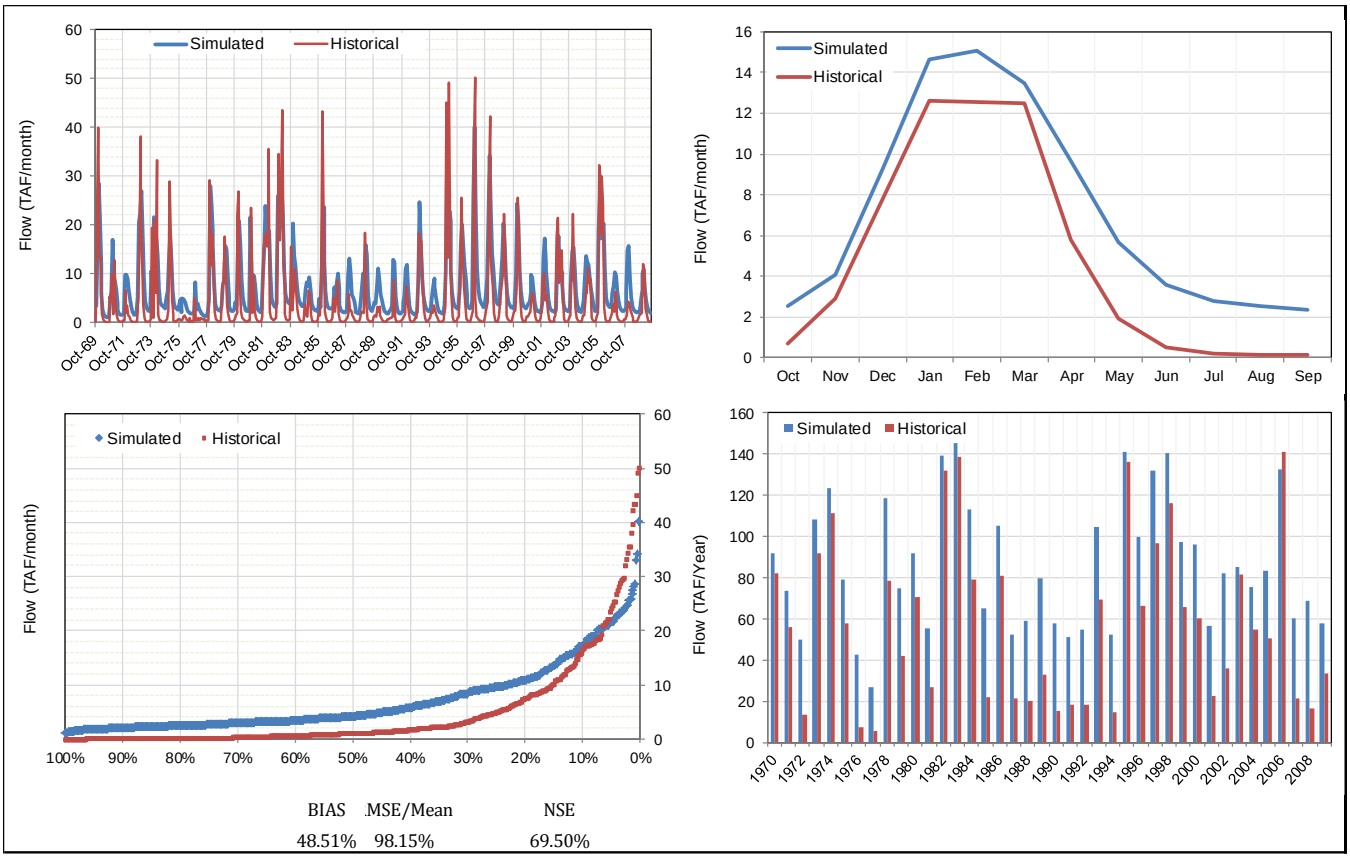

Figure A-18 Dry and Hutchinson Ck

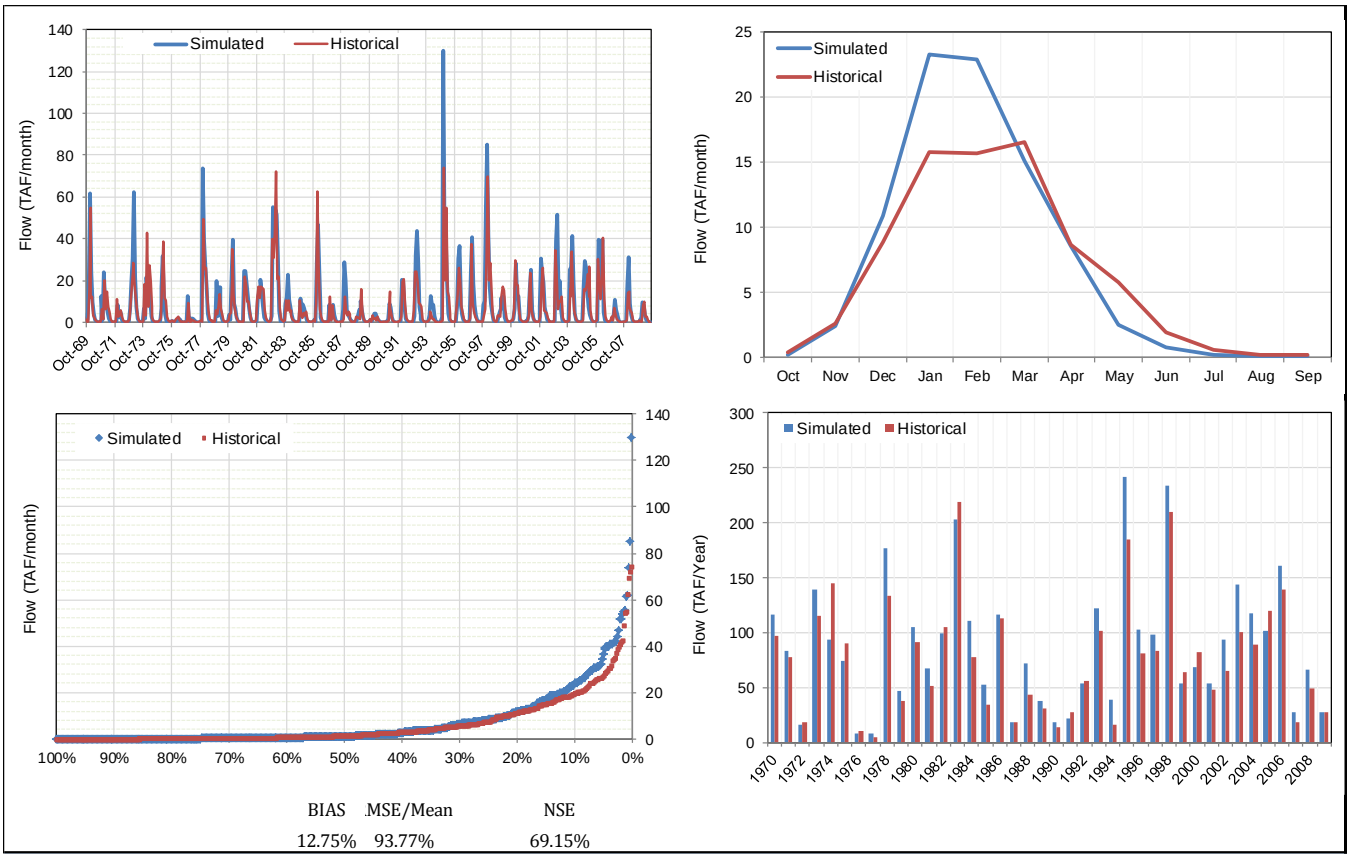

Figure A-19 lder Ck nr Paskenta

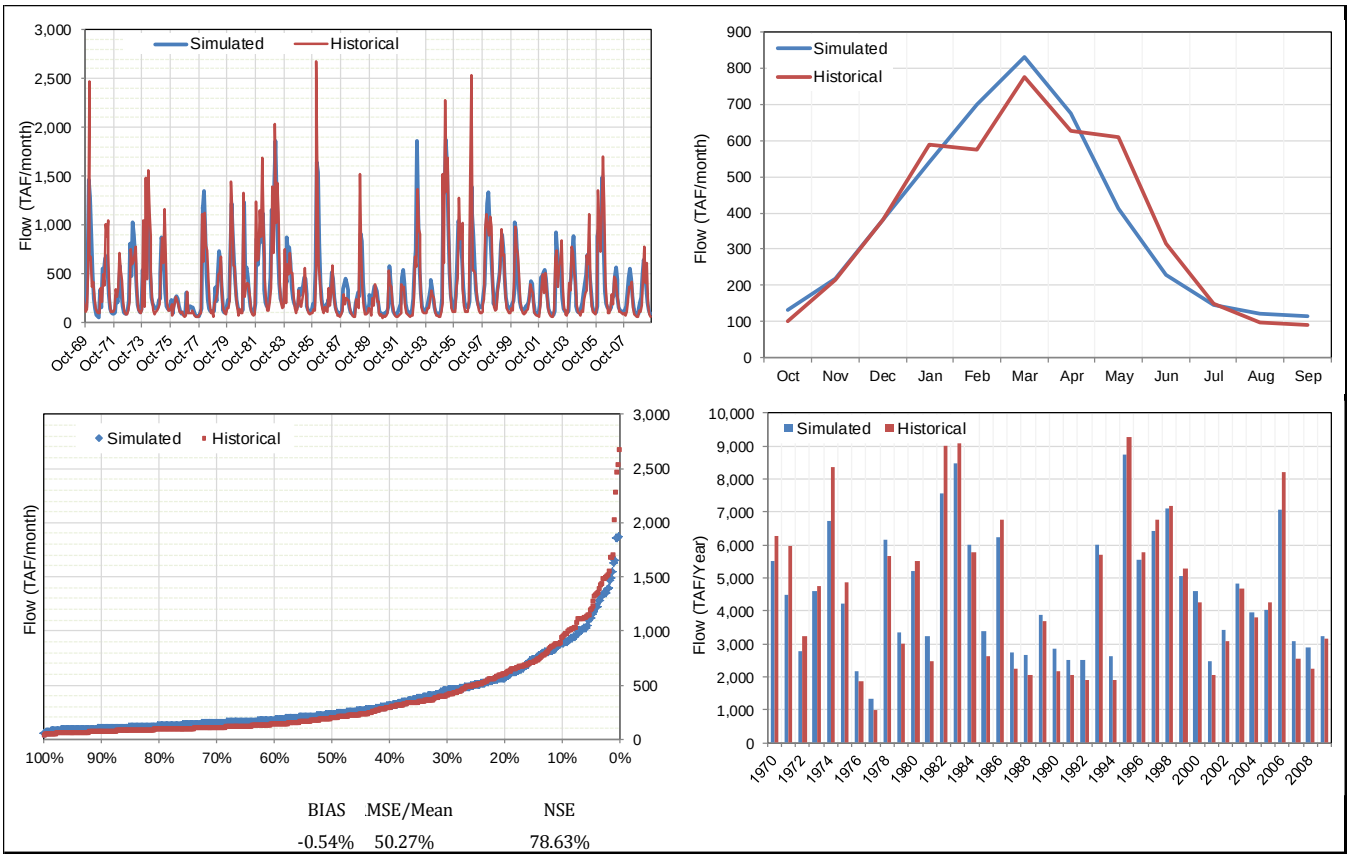

Figure A-20 Feather at Oroville

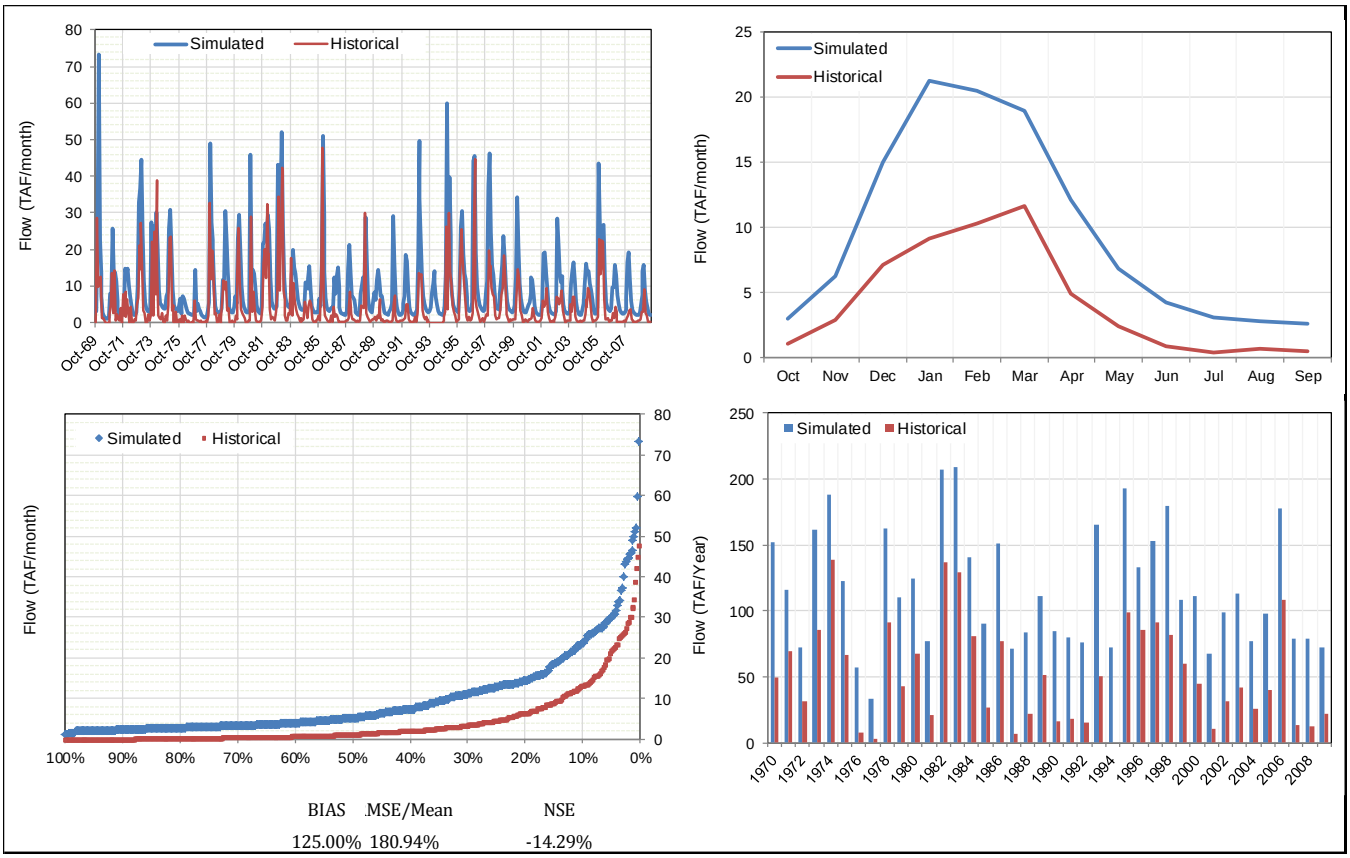

Figure A-21 French Dry Creek (Merle Collins Inflow)

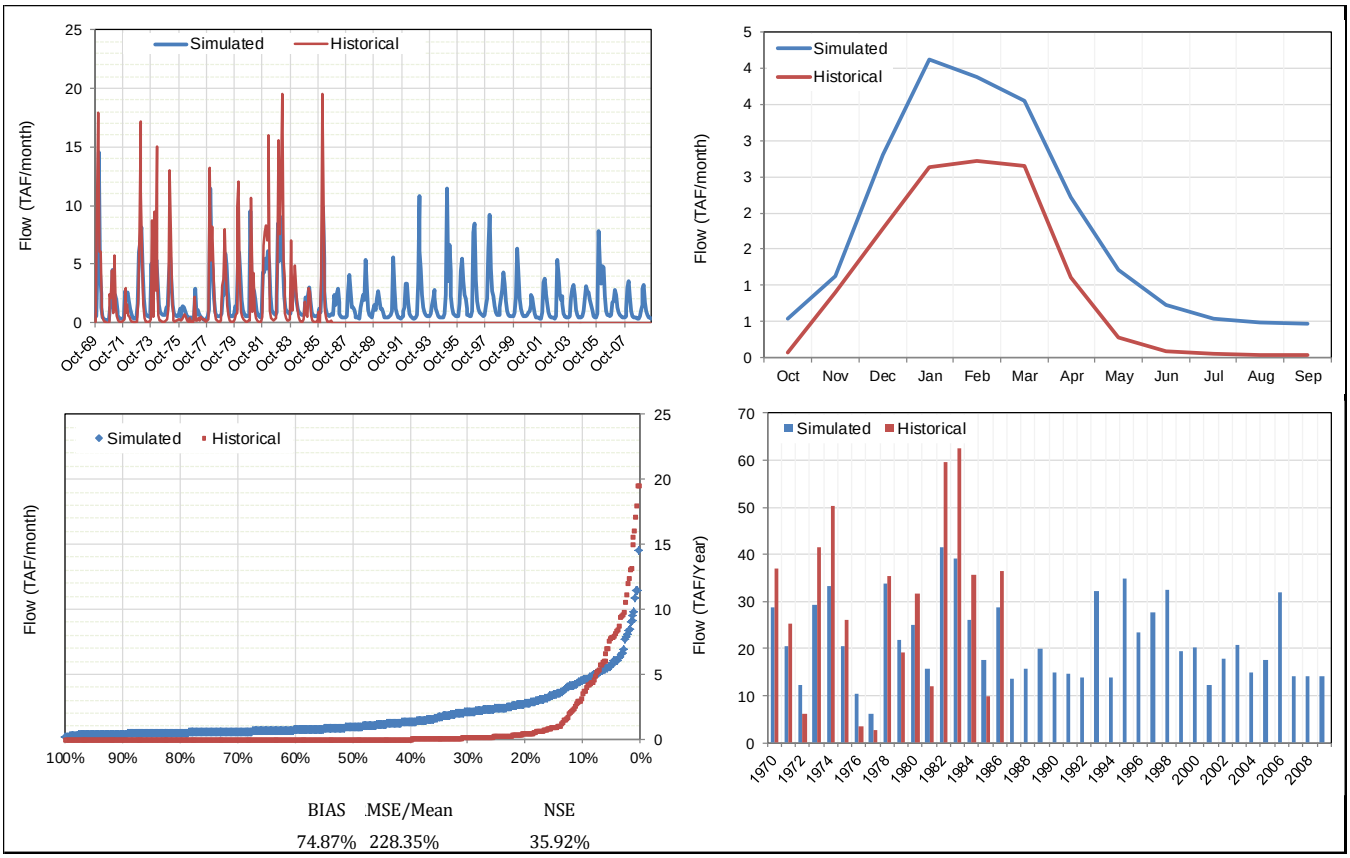

Figure A-22 S Honcut Ck nr Bangor

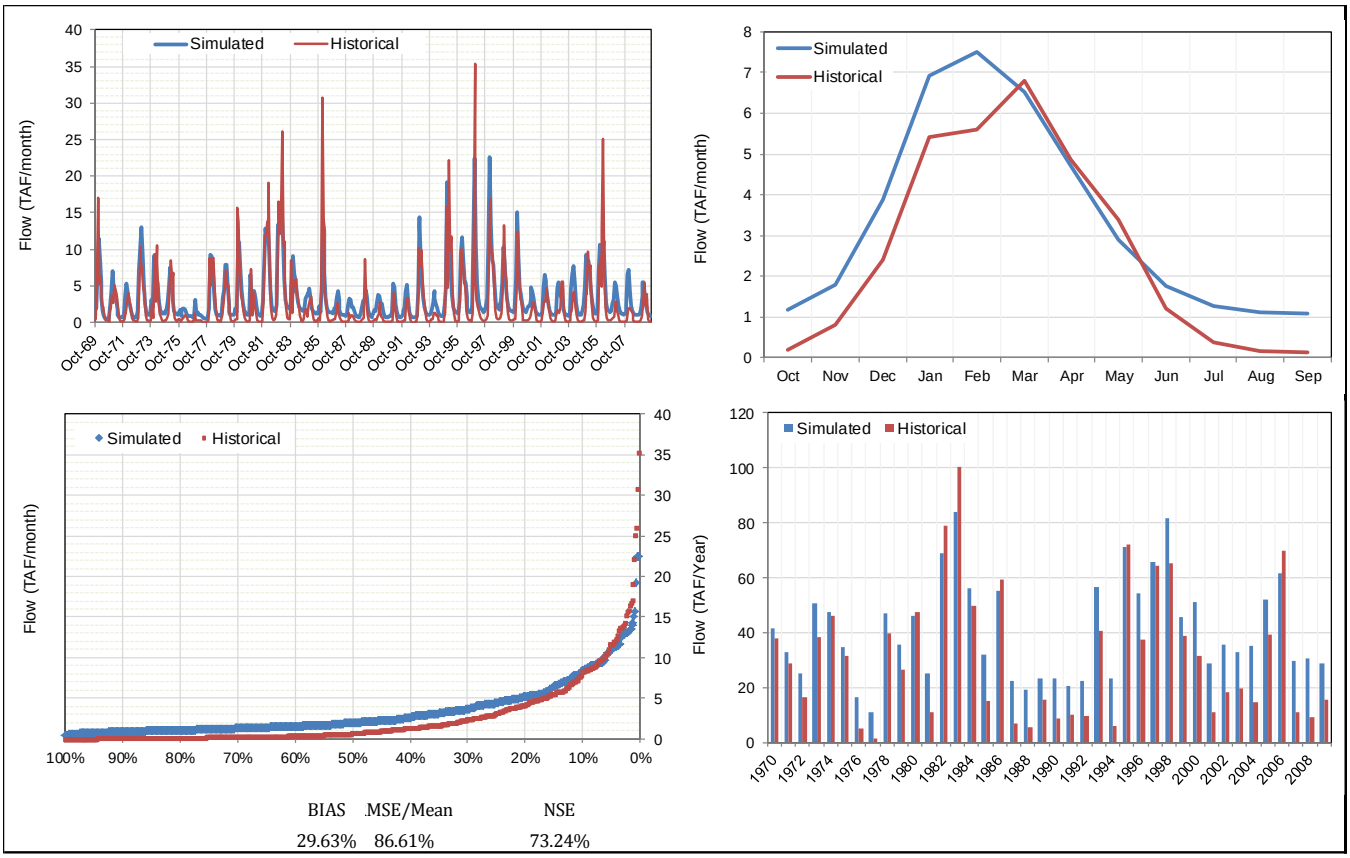

Figure A-23 Jackson Creek (Amador Reservoir Inflow)

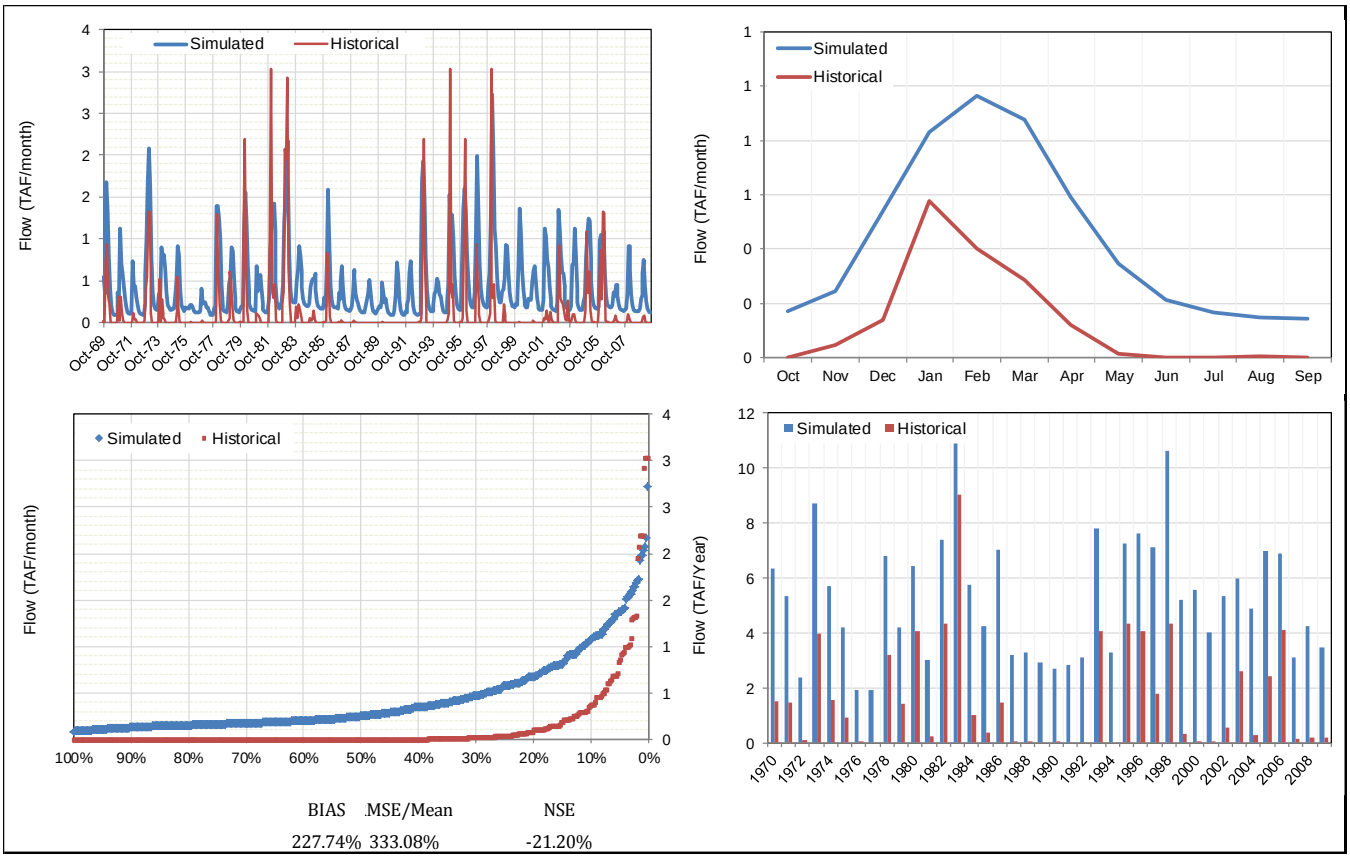

Figure A-24 Kellog Creek (Los Vaqueros Reservoir Inflow)

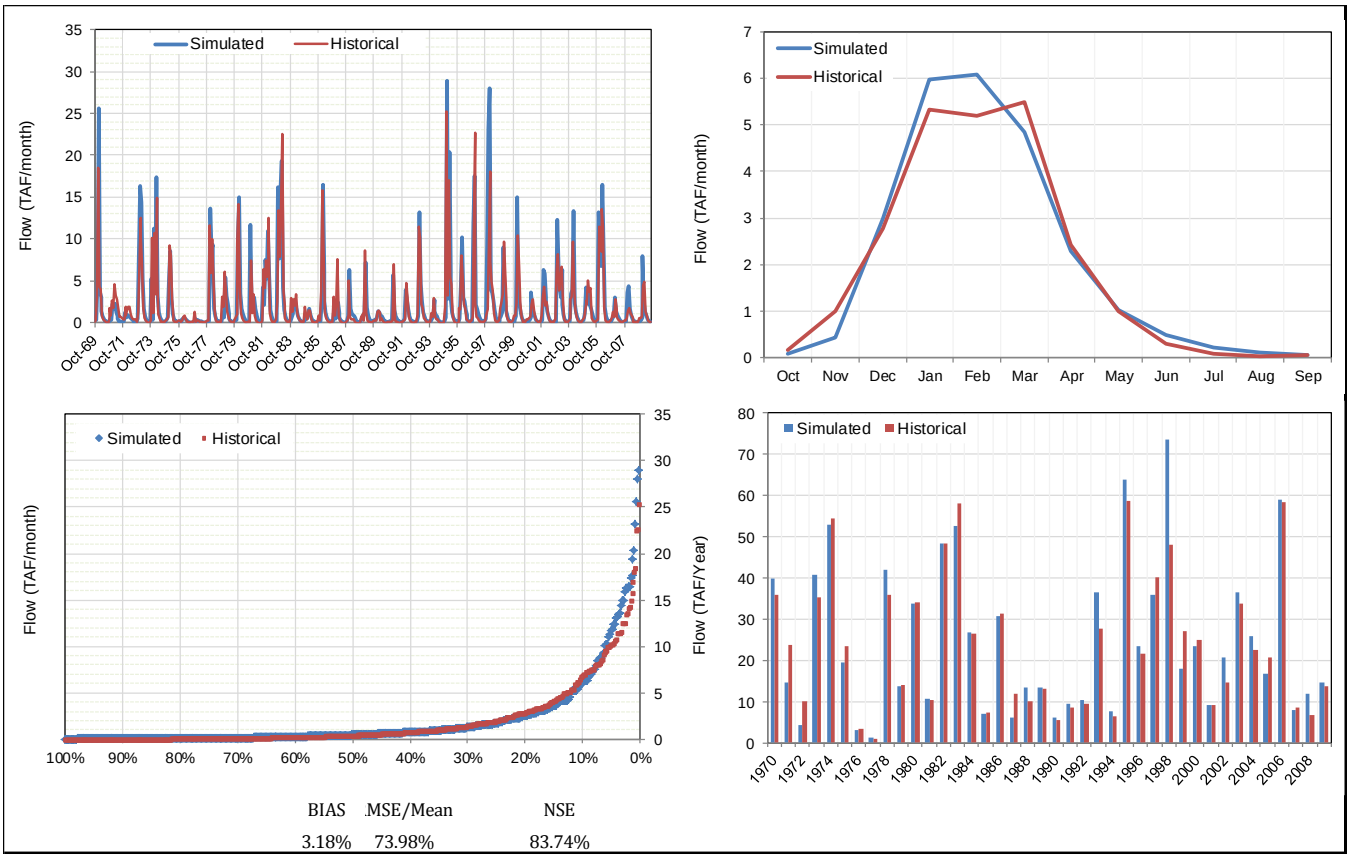

Figure A-25 Little Chico Ck at RM 38

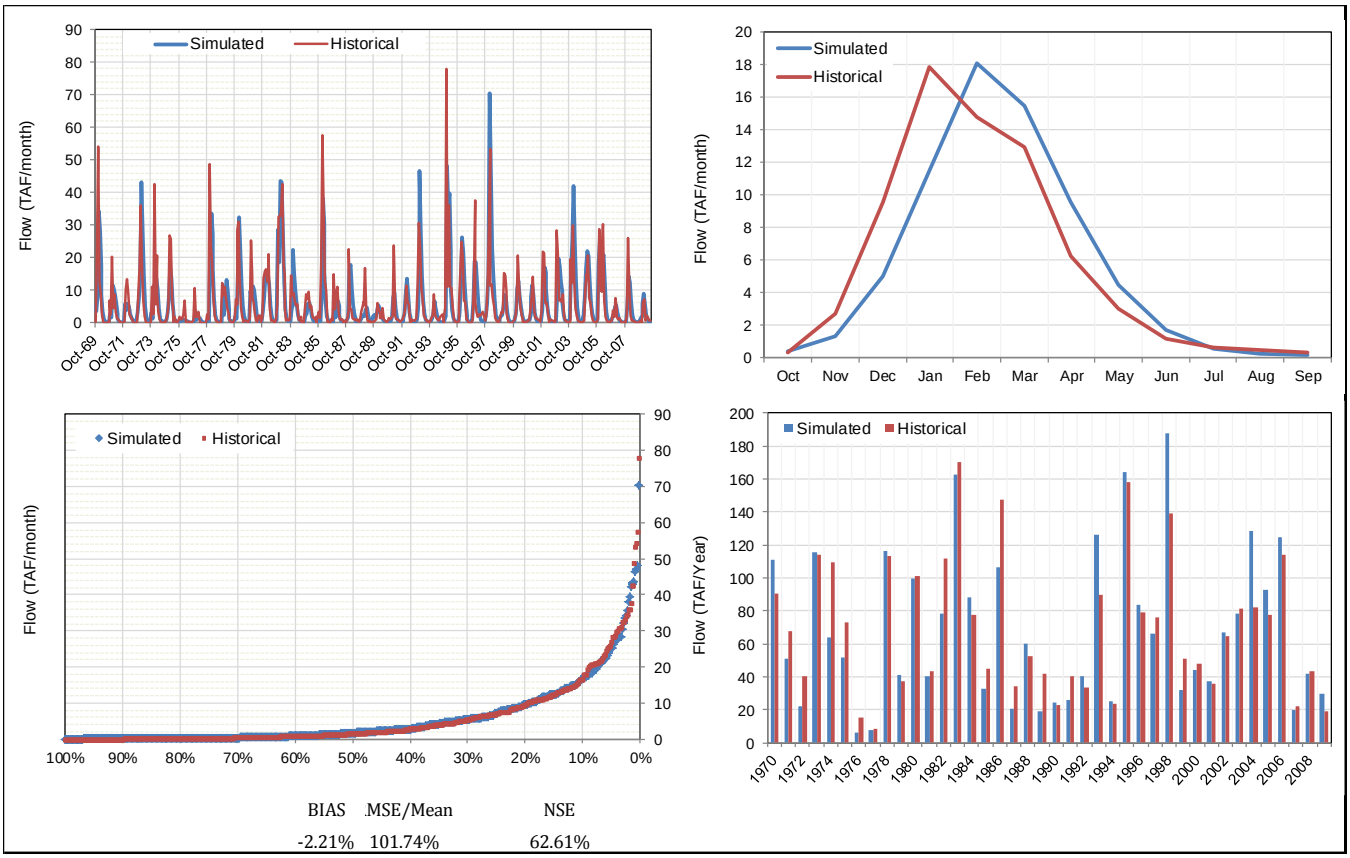

Figure A-26 Little Stony Creek (East Park Reservoir Inflow)

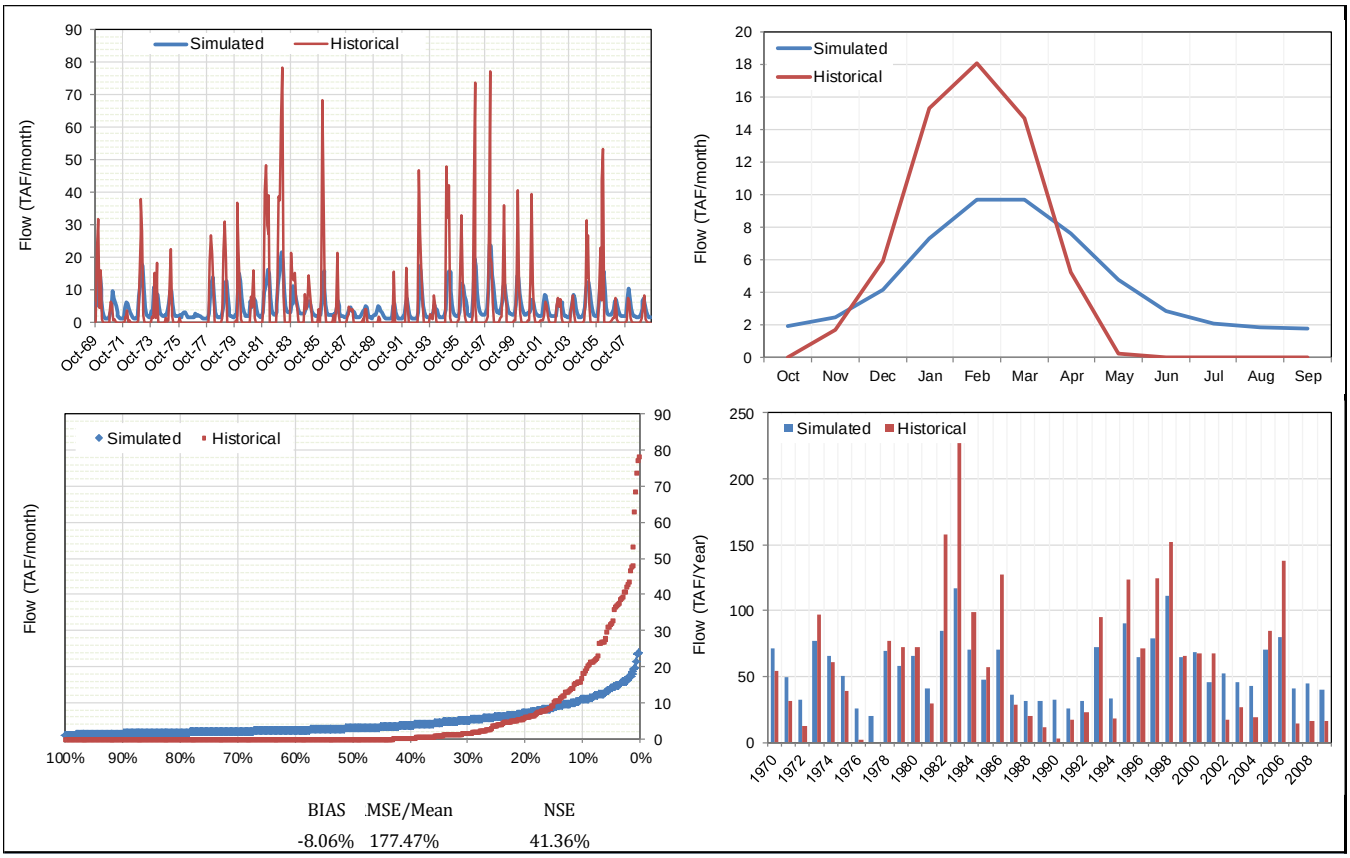

Figure A-27 Littlejohns Creek (Farmington Reservoir Inflow)

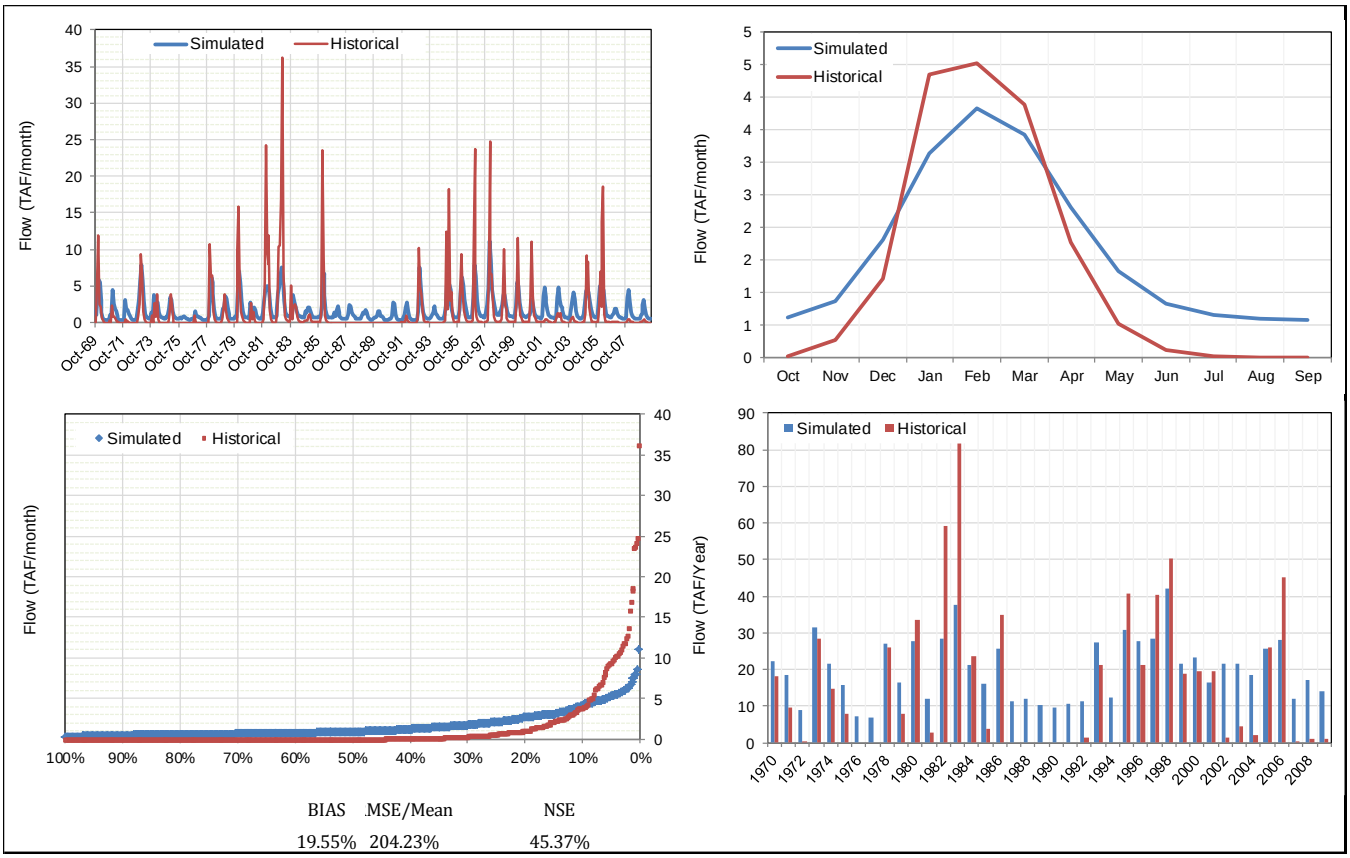

Figure A-28 Marsh Ck at RM 15

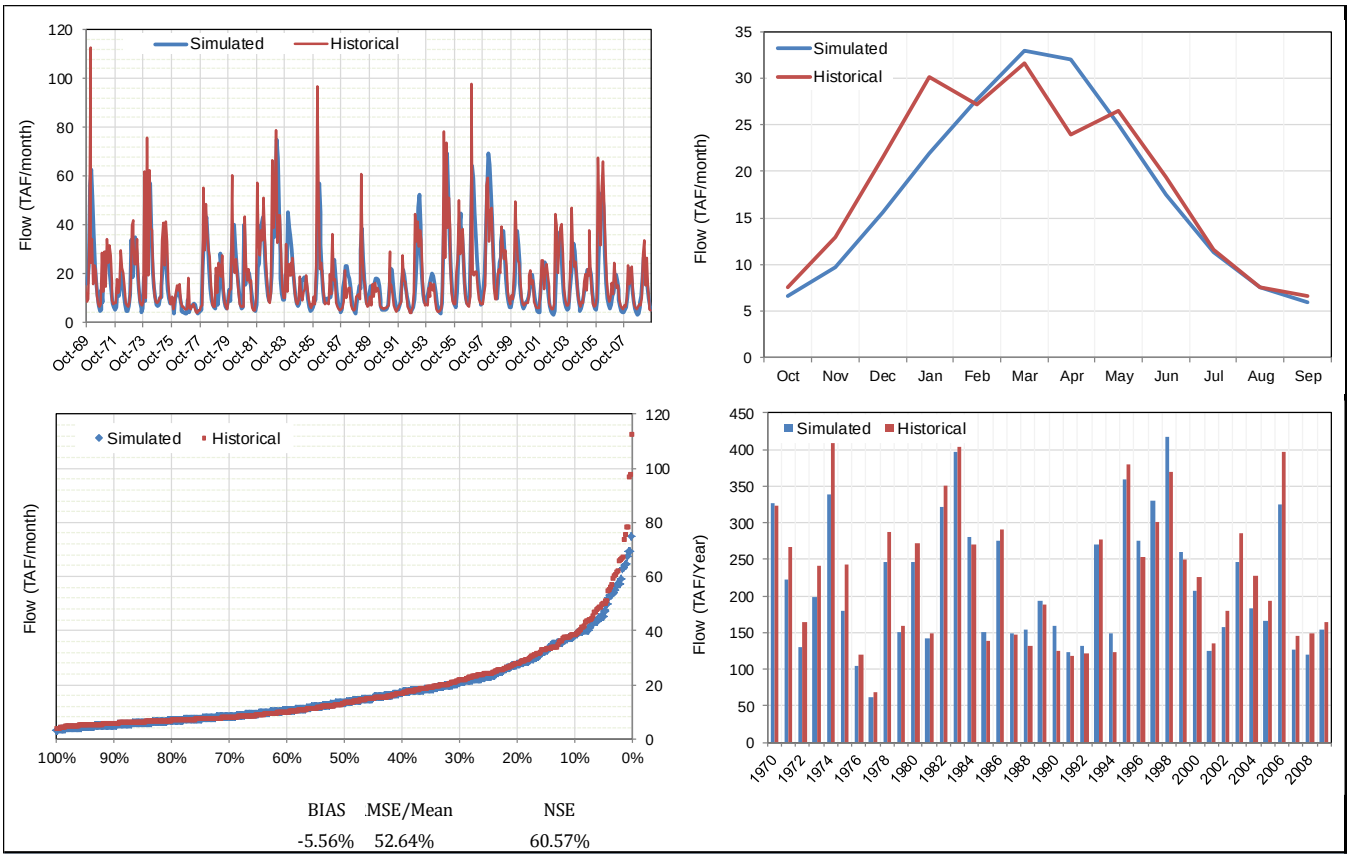

Figure A-29 Mill Ck nr Los Molinos

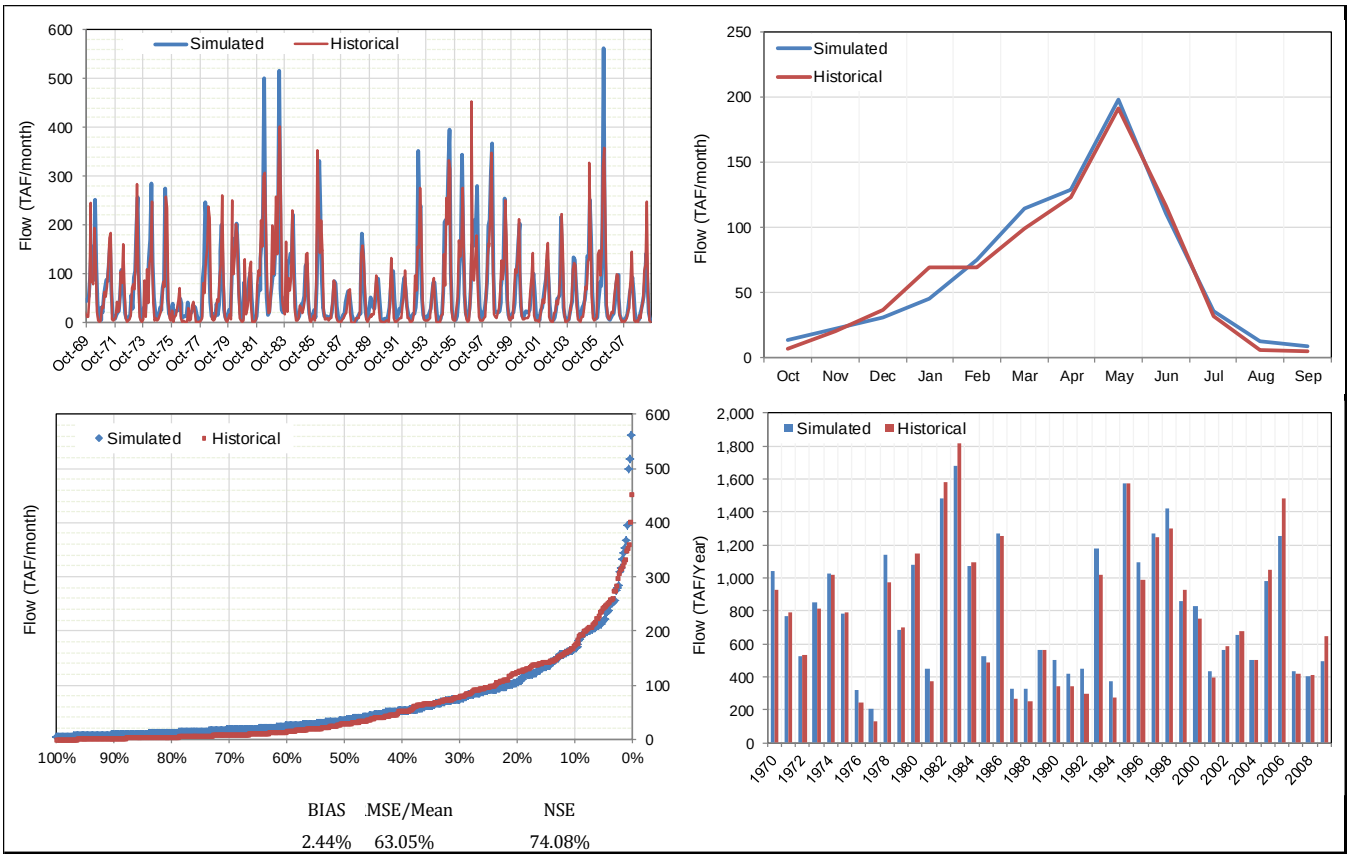

Figure A-30 Mokelumne River at Pardee

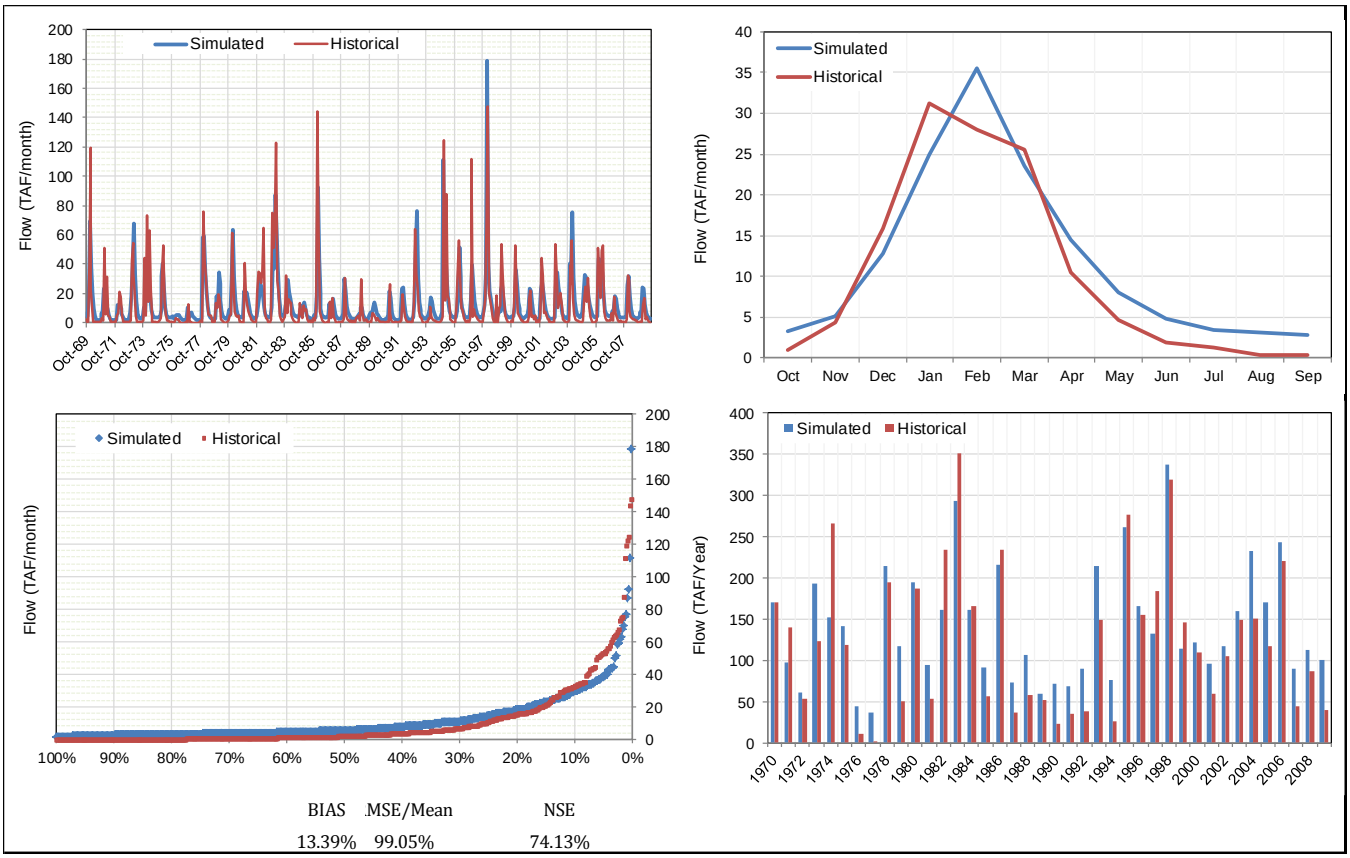

Figure A-31 North Fork Cache Creek (Indian Valley Reservoir Inflow)

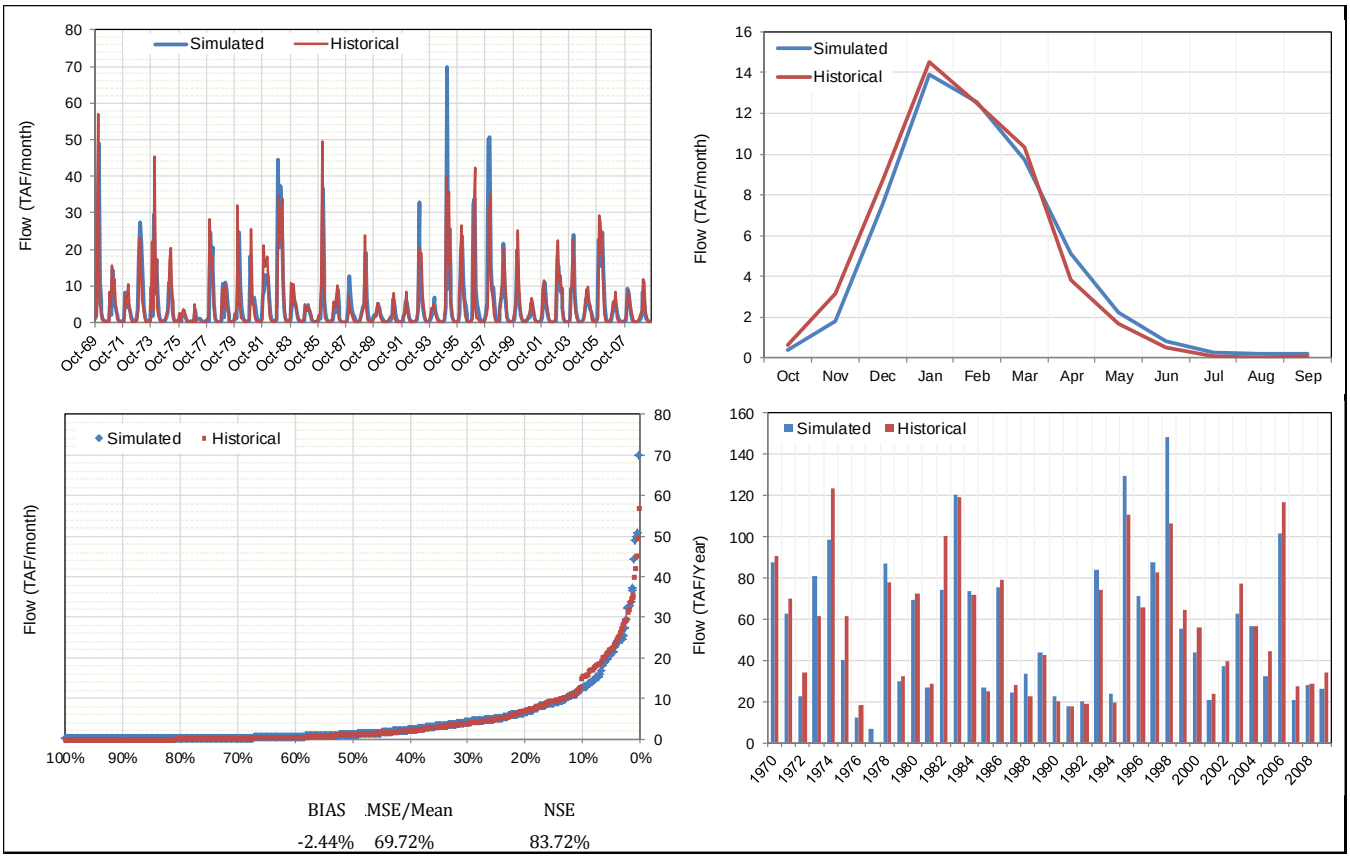

Figure A-32 Paynes and Sevenmile Cks

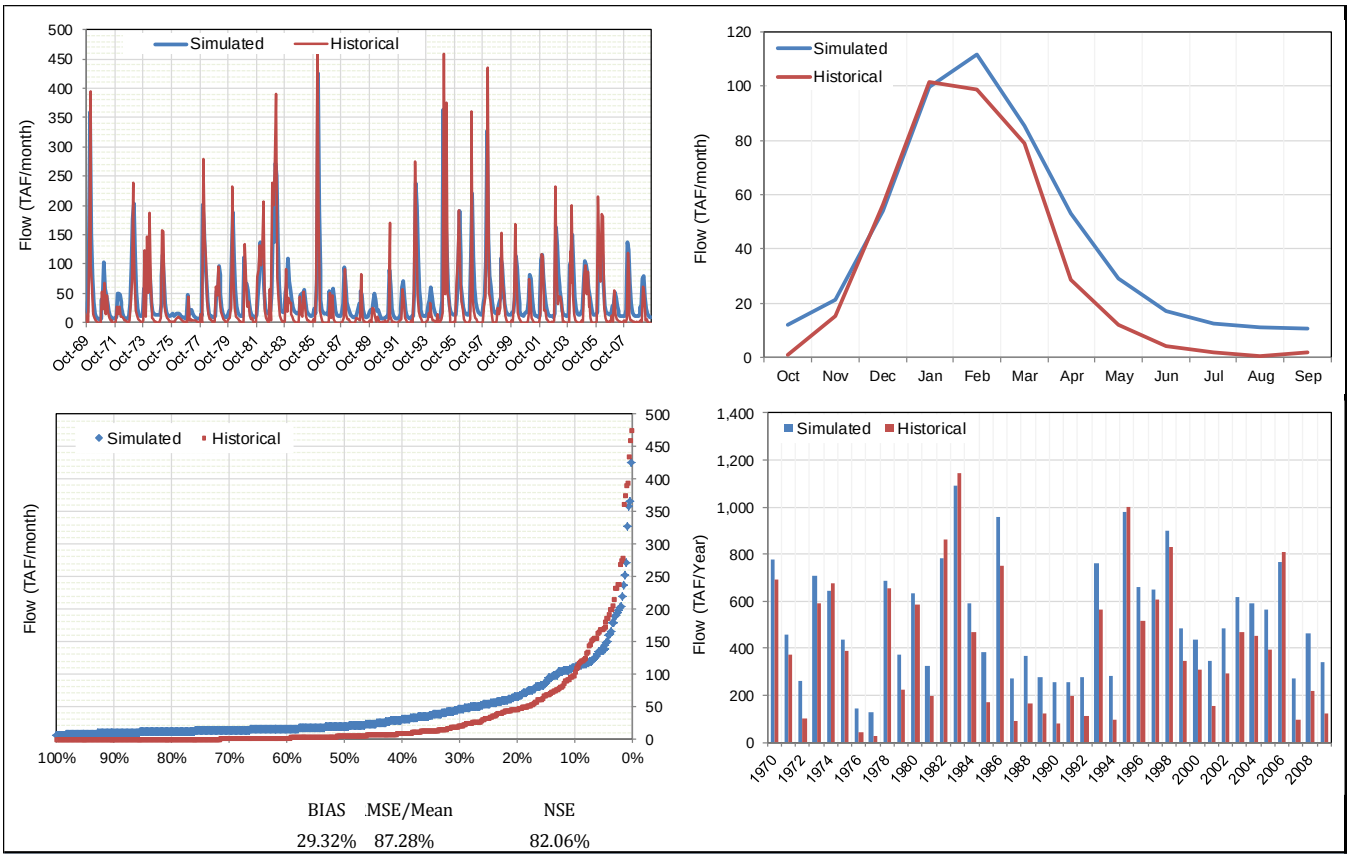

Figure A-33 Putah Creek (Lake Berryessa Reservoir Inflow)

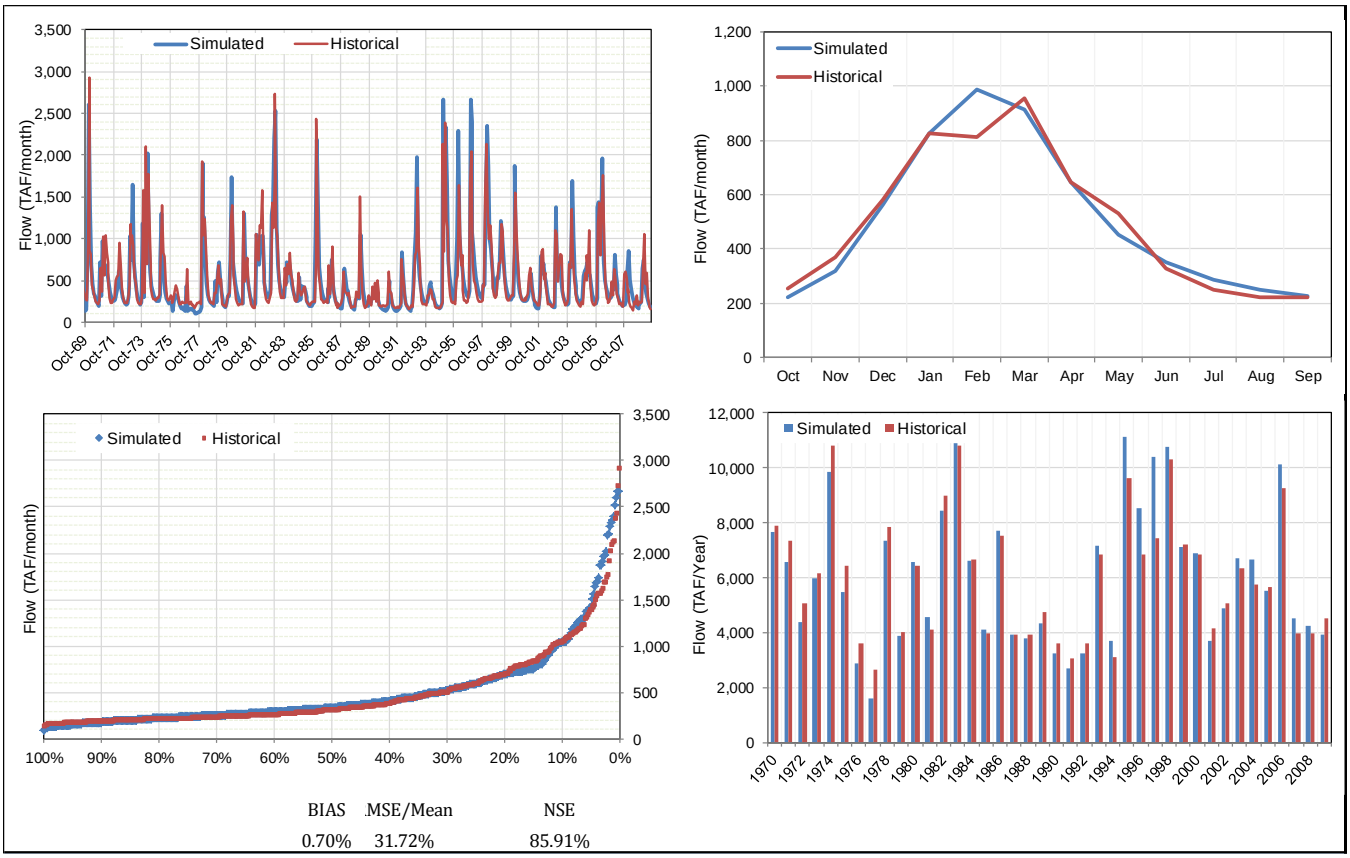

Figure A-34 Sacramento River (Shasta Lake Reservoir Inflow)

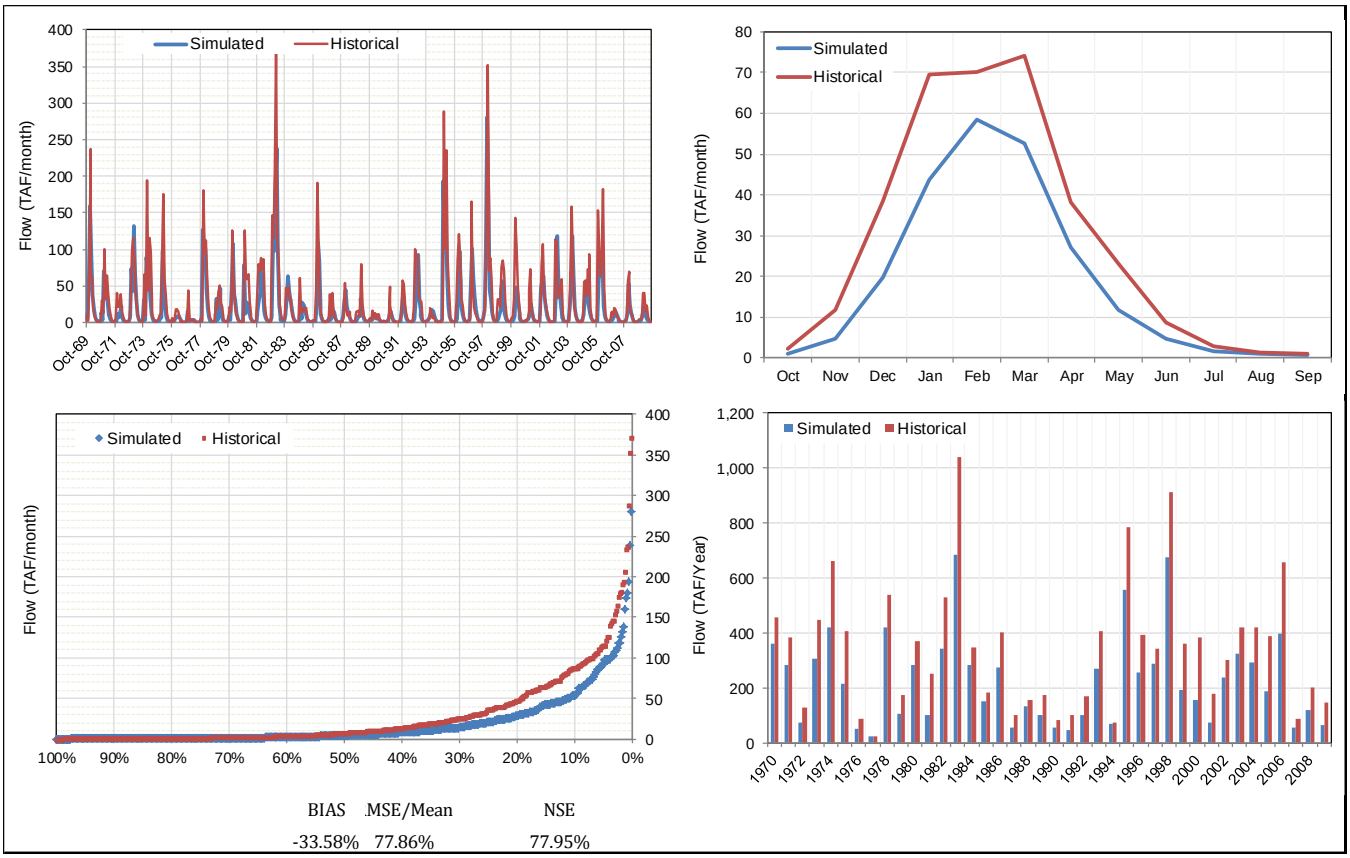

Figure A-35 SF Cottonwood Ck nr Olinda

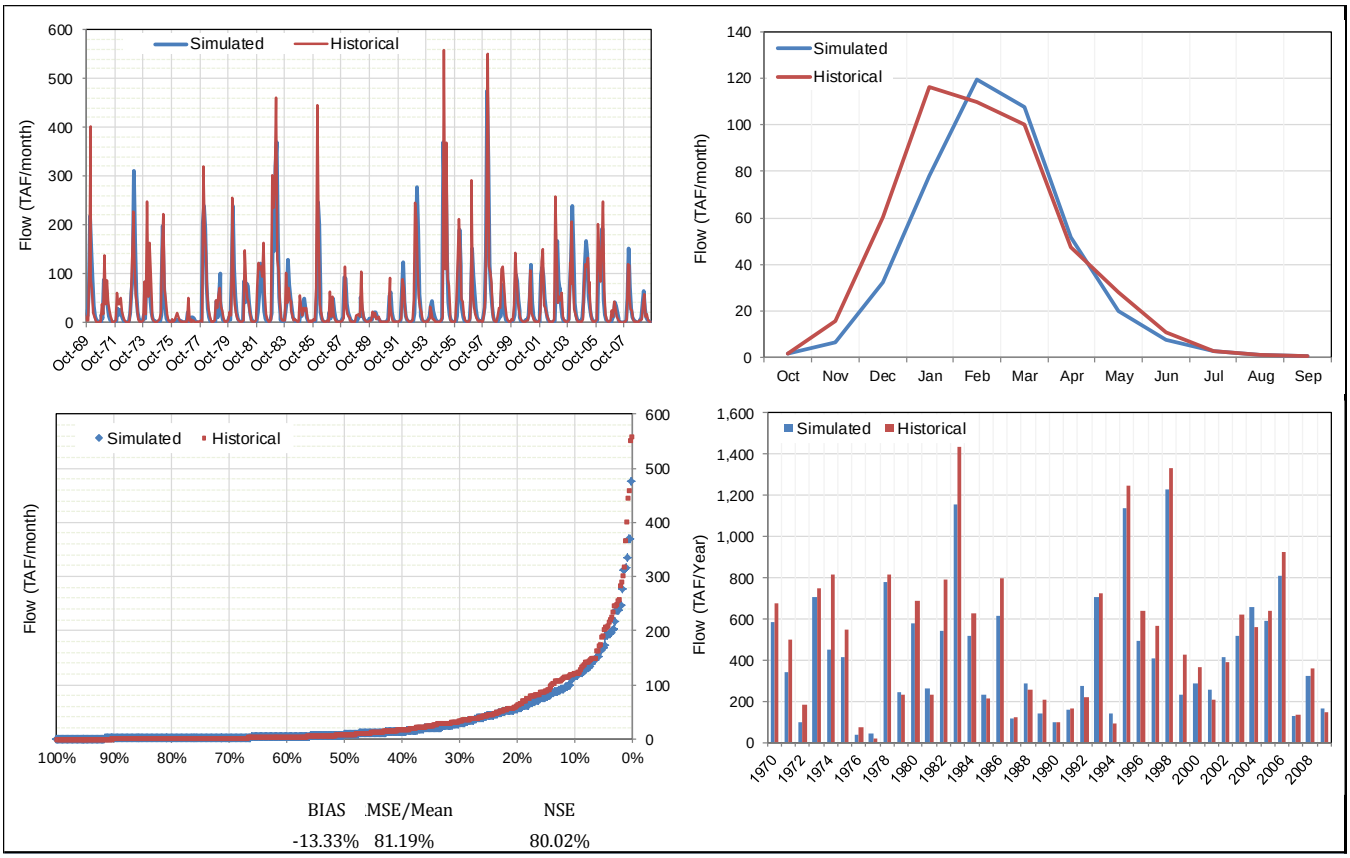

Figure A-36 Stony Ck at Black Butte

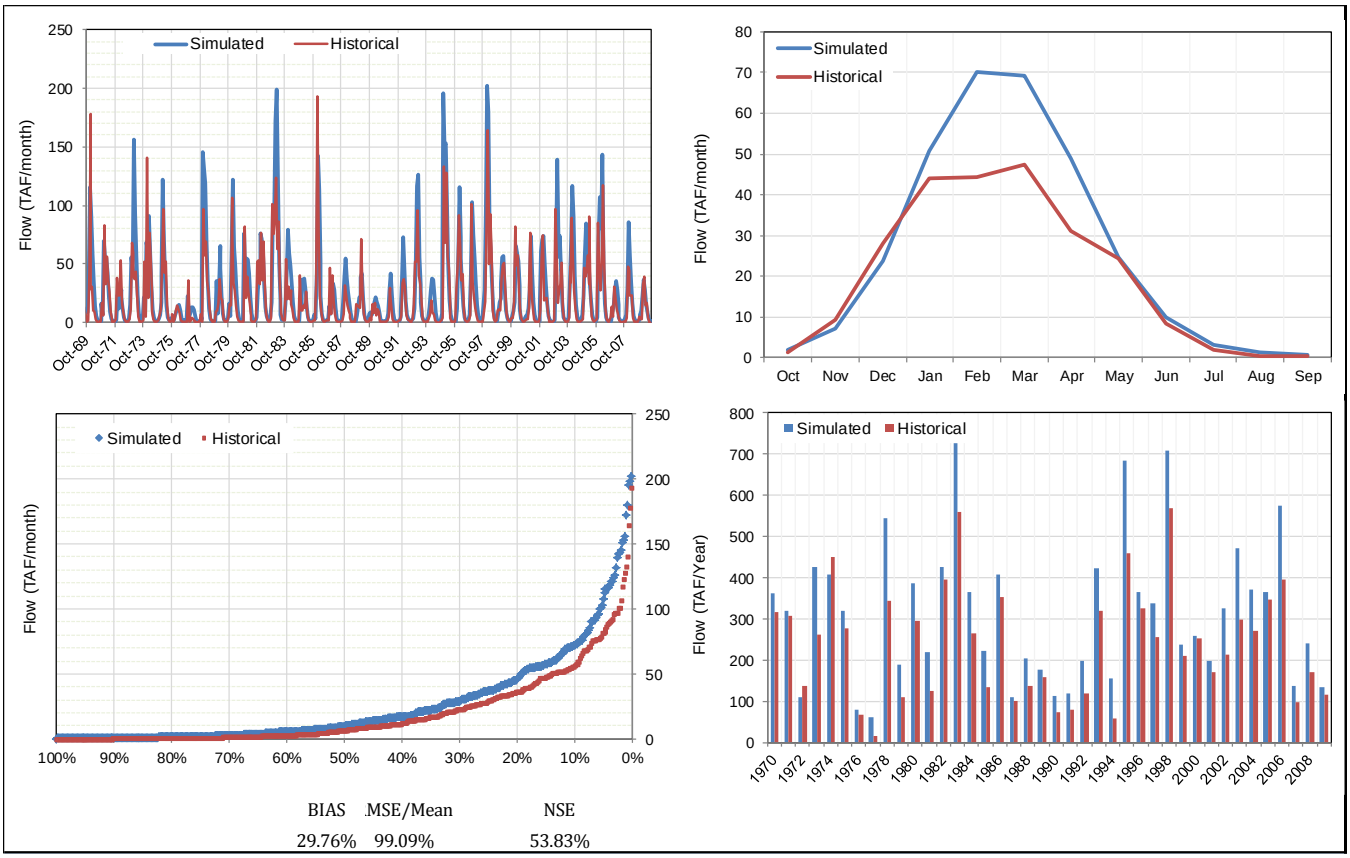

Figure A-37 Thomes Ck at Paskenta

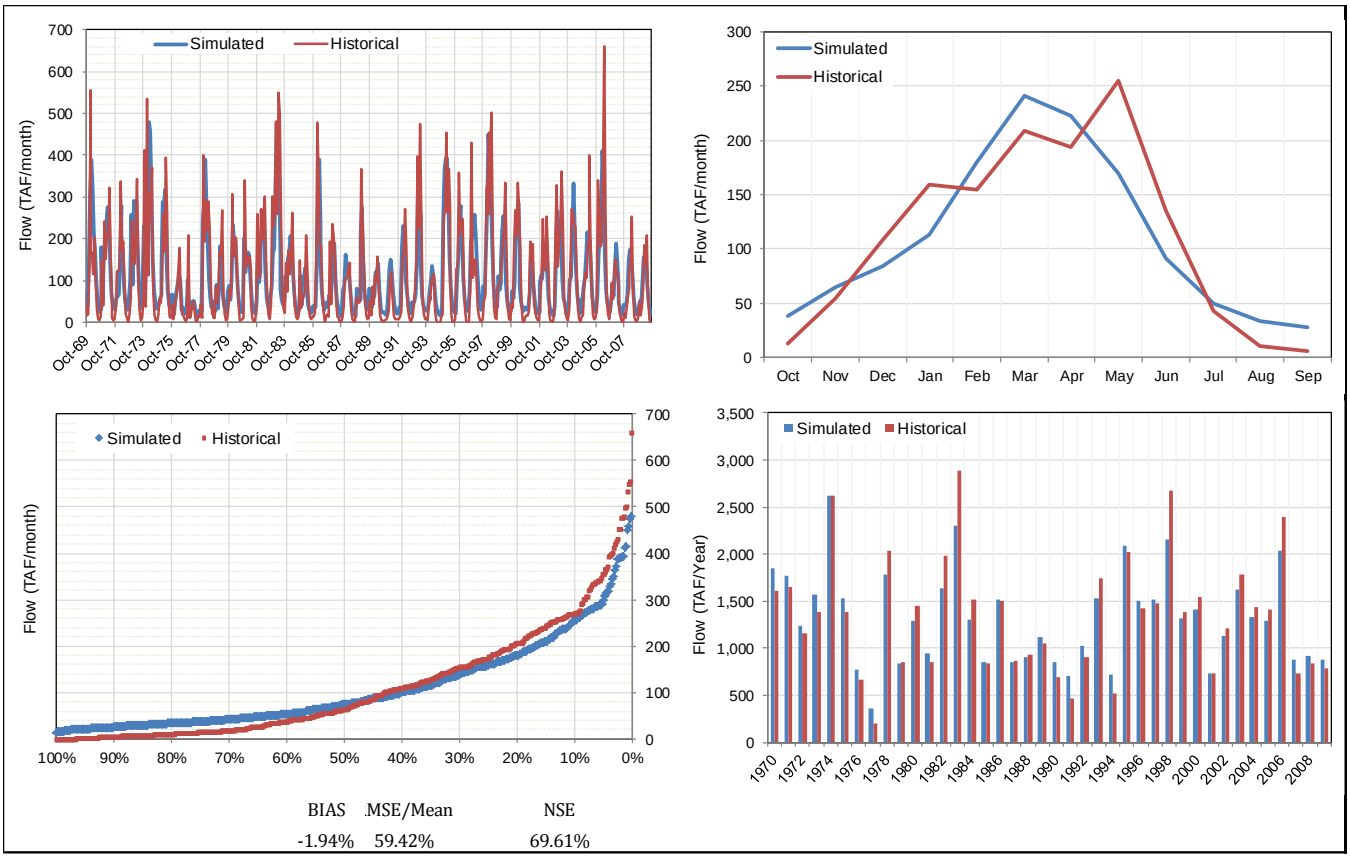

Figure A-38 Trinity River (Trinity Reservoir Inflow)

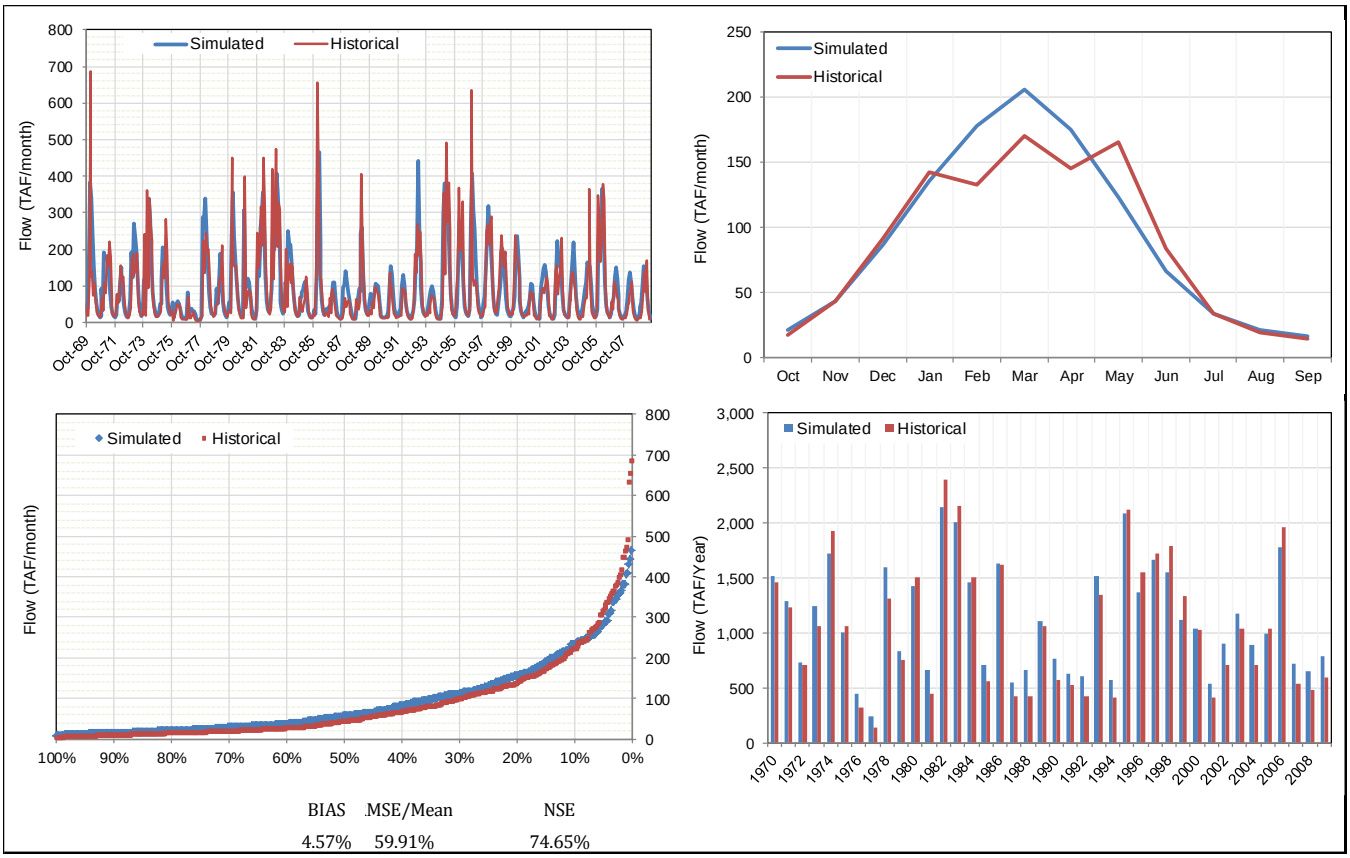

Figure A-39 Yuba River (New Bullards Bar Reservoir Inflow)

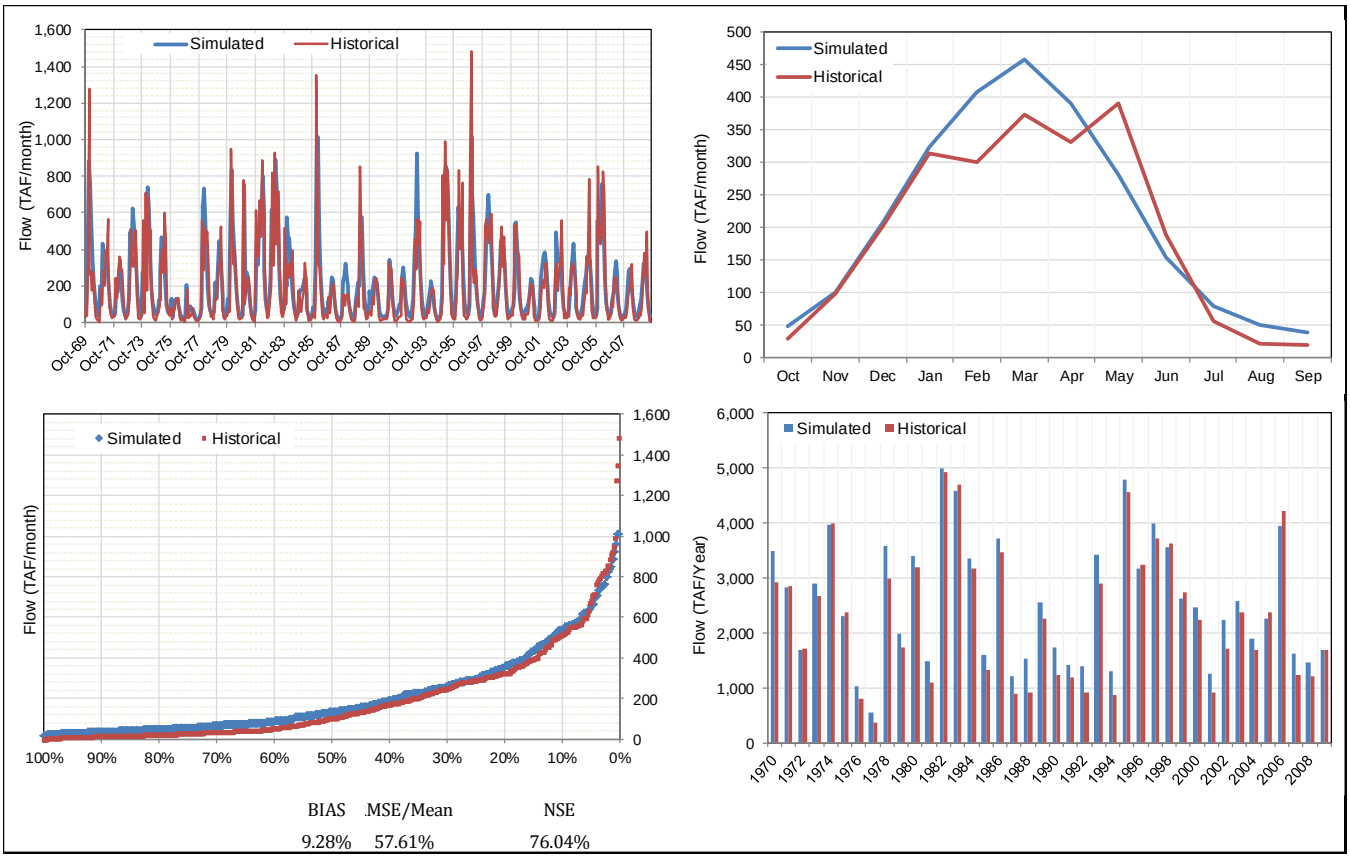

Figure A-40 Yuba River at Smartville